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LEVELLING
AND ITS GENERAL APPLICATION

THOMAS HOLLOWAY

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LEVELLING

AND ITS GENERAL APPLICATION

(*THIRD EDITION*).

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ITS GENERAL APPLICATION

(*THIRD EDITION*)

BY

THOMAS HOLLOWAY,

AUTHOR "OF THE PRACTICAL SURVEYOR," ETC.

REVISED BY H. T. TALLACK.

"Much depends as in the tiller's toil
On culture and the sowing of the soil."
COWPER.

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PREFACE TO THIRD EDITION.

Having been asked to prepare for the press this third edition, I have endeavoured to follow as closely as possible the simple, yet practical explanations of the author. I have carefully read over the whole work, and have made a few additions and alterations merely with the view of bringing it up to date, as some improved methods have been introduced since the previous edition was published.

H. T. Tallack.

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LEVELLING

AND ITS GENERAL APPLICATION.

CHAPTER I.

Importance of the Art of Levelling — Difference between Apparent or Optical Level and True Level — Curvature of the Earth — Questions of Levelling affected by this.

THE art of levelling is one of those generally useful branches of engineering which, associated as it is with the law of gravitation, applies itself in a greater or less degree to almost every object that the vision can embrace.

It is only by the application of levelling in combination with the law of gravitation that the equilibrium of any construction can possibly be maintained ; and as it is only by this application that the laws which govern construction and mechanical motion can possibly be understood, it must for all time hold its own, and of necessity demand the attention of the student.

Levelling, as applied to actual practice is, on the one hand, the determination of the *apparent or optical level,* which is simply the earth's tangent extended in space, or, in other words, a line drawn at right angles from its point of contact with the earth's circumference to a line drawn from the point of such contact to the centre of the earth, and which may be expressed with greater clearness as the earth's radius or direct line of equal gravity ; on the other hand, it is the determination of the *true* level which may be described by the arc of a circle radiating from the centre of the earth ; it also comprises a comparative determination of all the elevations and depressions which form the natural inequalities of the earth's surface.

Fig. 1 is illustrative of the line of *apparent or optical level* —*A* being the point of contact, *B* the centre of the earth, and *C C* the earth's mean circumference.

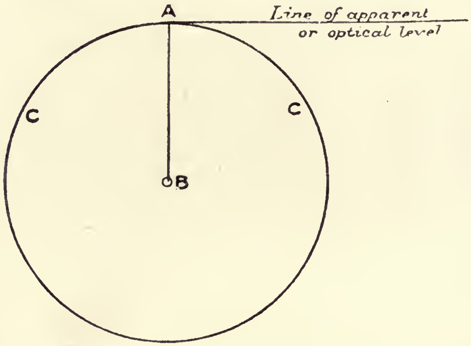

FIG. 1.

Fig. 2 is illustrative of the line of *true* level—*A* being the centre of the earth, *b b b* being an arc of the earth's mean circumference.

To the quite uninitiated it may appear strange that a truly level line should be illustrated by the arc of a circle ; but when we consider that a truly level line further means the sectional line of the exact surface of a vast area of water in every part motionless—and that by sectional line we understand such a line of the surface of the water as would be

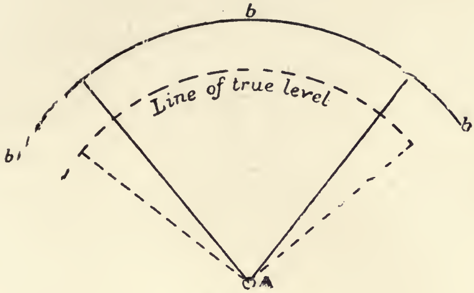

FIG. 2.

visible were the water a solid and vertically divided—we shall find it not at all strange, because we know that the surface of motionless water is at all points practically equidistant from the earth's centre, in accordance with the law of gravitation ; and we further know that the earth is spheroidal.

Now let us follow this part of our subject to a simple practical test, and to do so assume that we are on a known long straight level of canal—say in Bedfordshire—and that the surface of the water is of a glassy stillness, and the atmosphere clear and free from mirage.

At points *A*, *B*, and *C* alongside the edge of the canal (Fig. 3), which points for the sake of argument shall be a mile apart, erect rods having a transverse top to them, in the form of the letter **T** (technically boning rods), exactly 3 feet above the surface of the water. Now if there were no difference between the *apparent or optical* level and the *true* level, and if the earth were a plane and not a sphere affected by the law of gravitation, the tops of the rods would be in a straight line of sight and parallel to the surface of the water, as also shown in Fig. 3.

The fact, however, is that three rods so erected would not range in a straight line of sight, but would appear as

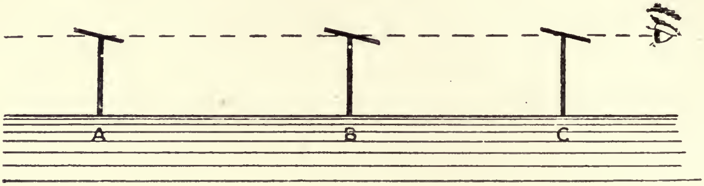

FIG. 3.

shown diagramatically in Fig. 4, thus ocularly demonstrating the facts that the form of the earth is spherical, and that the surface of a liquid at repose is at all points practically equidistant to or from the earth's centre.*

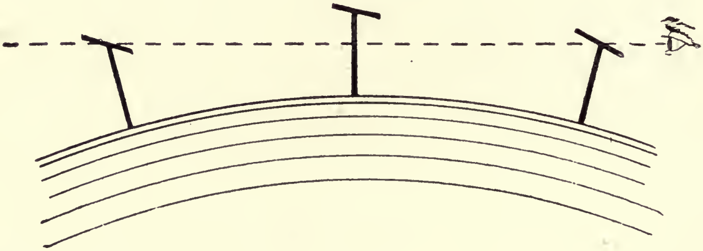

FIG. 4.

Admitting at once the convexity of the surface of the earth, and consequently that there is an important difference between the apparent or optical level and the true level, let us consider for purposes of practical application the value of such difference. The mean diameter of the earth—*i.e.*, the average between the polar diameter and the diameter taken at the equator—is 7,916 miles ; and the square of the length of any measured distance in miles divided by the earth's mean diameter, or 7,916 miles, will give the amount of depression to be allowed from the actual level line of sight in respect of the curvature of the earth. The following example will, I think, simplify this matter much.

---

*Ptolemy's theory to the contrary was upset by Copernicus in the 16th century. Better authorities are Newton and La Place.—T.H.

Required the difference between the apparent or optical level and the true level for a distance of one mile between the points *A* and *B* in the annexed diagram (Fig. 5).

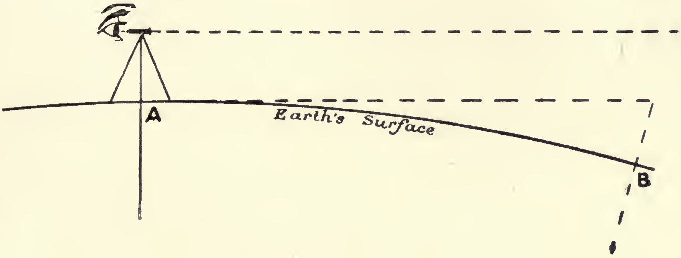

FIG. 5.

1 mile squared = 1, which divided by 7,916 = $\frac{1}{7916}$ of a mile, or 0.667 feet, or practically 8 inches.

Required the difference between the apparent and true level when the distance between *A* and *B* (Fig. 5) shall be three miles. $3^2 = 9 \div 7916 = \frac{9}{7916} = .001137$ miles = 6 feet. Two examples are given to show that for all practical purposes 8 inches may be considered as the difference for one mile, but the difference increases in proportion to the square of the distance; thus, at two miles the difference would be four times as much as at one mile; at three miles nine times as much as at one mile; at four miles sixteen times as much as at one mile; and so on. When the distance is given in yards, multiply the square of it by 2.57, and divide the result by 1,000,000, when you will have the difference in inches;

and when the distance is given in chains, divide the square of it by 800, when the quotient will show the difference in inches. It must, however, be observed that as no man can take an observation from the ground, without probably digging a hole to get into, and clearing a quantity of the natural production of the soil, the height at which any instrument used for the purpose of taking an observation of this kind is placed above the ground must be taken into consideration, because the line of sight taken with an instrument will be parallel to a line of sight taken from the ground, but so much higher. Reference to Fig. 5 will explain this.

Although it is well that the student should quite understand the foregoing, he will in actual practice seldom, if ever, be called upon to make allowances in respect of the curvature of the earth. In small matters curvature is so trifling that it can be disregarded, and in larger ones it is balanced by that method of using the level on the tripod which is hereinafter described.

CHAPTER II.

THE SPIRIT LEVEL PURE AND SIMPLE—BONING RODS—MECHANICS' LEVELS—LEVEL WITH FOLDING SIGHTS—REFLECTING LEVELS.

WE will now give a description of some of the instruments in general use for determining simple and direct levels, and the methods of applying them to their several uses, before entering upon the subject of levelling with the only really reliable instrument, the level on the tripod.

The spirit level is a curved tube of glass nearly filled with pure alcohol, chloroform or ether, and hermetically sealed at both ends, so that when held with its centre in a truly horizontal position, the vacuum, or more correctly the part of the tube not filled with alcohol, forms a bubble on the centre of the upper or *highest part* of the tube. When the bubble is not in the centre of the tube—that is, in the centre of "its run," as generally expressed—the tube is not in a horizontal position. The curvature of an accurate bubble tube is formed by grinding the inner surface of the glass with emery. This grinding leaves it covered with very minute scratches, which add greatly to the sensitiveness of the bubble by their capillary action.

Owing to the expansion of the alcohol by heat, and its contraction by cold, the bubble will become shortened in warm and elongated in cool weather; and to meet this variation, the tube is often graduated from its centre by transverse lines scratched upon it with a diamond, or etched by acid.

The simplest form of spirit level is that used by mechanics, and known as the "mechanics' level." This level, although occasionally mounted by the workman in accordance with some particular view of his own, is generally mounted in some hard wood or brass, and partly enclosed on the upper surface to protect it against accident, the lower surface of the mounting being parallel to the longitudinal centre of the tube. To ascertain if this spirit level be in adjustment, place it on the top of a short straight-edge, and by moving the latter bring the bubble to the centre of its run ; now, without moving the straight-edge, reverse the level, and, if the bubble still occupies the centre of its run, the level is in adjustment.

The straight-edge and "boning-rods" are frequently used in conjunction with the mechanics' level. The straight-edge in general use by mechanics is simply a strip of deal or pine, which should have two perfectly straight or parallel edges. The term "straight-edge" is, however, more often than otherwise quite an anomaly, inasmuch as it is rare to find one, in the truly correct acceptation of the term. As a broad rule, anything that is approximately straight and apparently parallel is accepted as a straight-edge, as, for instance, a piece of machine-shot flooring board.

It is, as far as my experience has taught me, always the better plan to have straight-edges made in pairs and shot together, for this reason—that, being subjected to precisely the same treatment, any inaccuracy in point of straightness appears doubled if the two edges are placed together and held quite on a plane against a strong light.

The boning rod is illustrated by Fig. 6, and may be of such dimensions as is most convenient.

A short line of level may easily be fixed by continuing the line of the bottom of the mounting of the level on the top of a straight-edge ; but a line of level may be continued to a greater length, and more easily, by the assistance of boning rods, and, *en passant,* no builder, surveyor, contractor, or engineer can do without them.

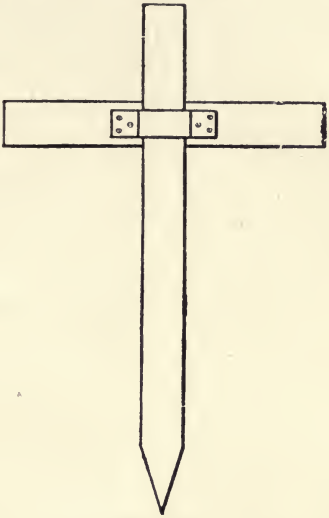

FIG. 6.

To set out a line of level with the mechanics' level and boning rods, set up a boning rod at the commencement of the line to be levelled, having its top at a perfectly transverse level to the line ; set up at 10 feet along the line a second boning rod, with the top transverse to the line to be levelled, and by means of the level and a straight edge a little more than 10 feet long (the latter being laid on the top of the first rod close to the upright), determine the level of the top of the first rod on the top of the second by marking it with a fine pencil on the upright, and adjust the slide and transverse level to the pencil-marking ; and in like manner from the second rod set up a third. Now if the operation has been nicely and carefully performed, the tops of the three rods will range in a perfectly straight and level line of sight, as shown by similar rods in Fig. 3. The line of level may now be produced to a moderate length by the addition of more rods, which can be set up by the eye at greater distances apart.

It must, however, be particularly borne in mind that *three* rods must always be truly erected before the continuation of the line by the eye, as a check against carelessness or inaccuracy. Two rods must of course always be in line, no matter whether applied horizontally or vertically.

The uprights of the boning rods should be stout and rigid, and the tops should be, for general uses, 3 feet long by 3 inches deep, and be painted white, or white and black, or white and red, in accordance with the dictates of necessity. The longer the tops of the boning rods, the better their application to curved lines; but when they are very long, they require supports at both ends, and thus become converted into what are professionally known as " sight rails."

Straight-edges, held in position by small heaps of clay or mortar, may be substituted for boning rods when the latter are not at hand. Some mechanics' spirit levels have sight holes through them, by the aid of which tolerably correct observations may be taken to moderate lengths. Some of these levels are fitted with screws for attaching them to long rules or straight-edges as shown at Fig. 7.

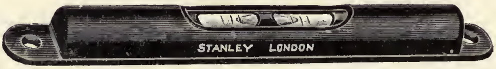

FIG. 7.

Very good work may be done with one of these fitted with sights as Fig 8 using a boning rod as a stand for it.

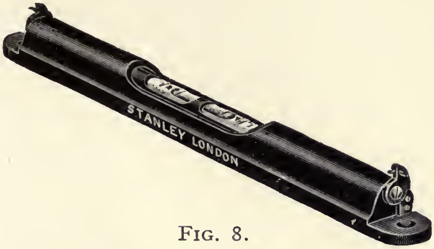

FIG. 8.

Another form of level which has for many years past held favour amongst drainage foremen is the level with folding sights, illustrated by Fig. 9. This instrument, although unquestionably useful for some special purposes, possesses so many weak points that I do not consider myself justified in recommending it as either a very reliable or durable one. As in the case of the mechanics' level with sight holes, the adjustment of this level may be tested by a transposition of the points of observation.

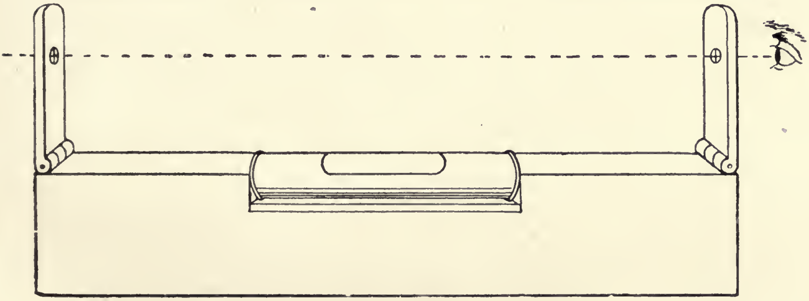

FIG. 9.

The reflecting level (Fig. 10) is a very valuable instrument. and being only 4 inches in length, can be conveniently

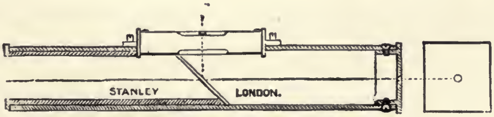

FIG. 10.

carried in the pocket. I have for some years carried one of these levels when engaged upon preliminary inspections, drainage, water supply, etc., and have obtained such results with it as have not been materially upset by detail, worked out to a nicety.

This reflecting level is so constructed that the reflection of the bubble, when in the centre of its run, appears as directly over the horizontal line in the reflecting plate which occupies half of the interior of the tube to the left of a vertical diameter, the remaining half of the interior of the tube being open for the observation of the point of level, which is indicated by the end of the horizontal line.

This instrument is extremely simple, and really requires no explanation, a steady hand being the only real essential to its correct application.

Another reflecting level is the balance level suspended on gimbals, illustrated by Fig. 11. This level, which can be quite as conveniently carried in the pocket as the former one, is, to my mind, one of the most simple

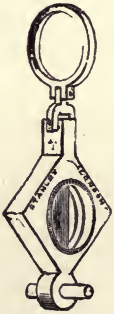

FIG. 11.

and effective for rough trial work over a new country that has ever been placed in the hands of the engineer. It is constructed upon the principle that a perfectly vertical mirror will reflect any object placed before it in a true horizontal plane. In the use of this instrument the pupil of the eye is made the object to be reflected, and the reflector, which is of parallel glass, is half silvered, so that half of the pupil of the eye may be brought for reflection upon the edge of the silvered part. By holding the level at arm's-length, and bringing the reflection of half of the pupil of the eye upon the reflector, an object seen through the clear part of the glass, which centres the reflection of the pupil, is on a true level with the eye of the observer.

As with the former instrument, steadiness is the chief essential to correct observation, and to obtain this it may be advisable to clutch a picket, alpenstock, or offset staff, the point of which shall be on the ground, or to sidle up to a tree or other object, for support.

I see no reason why this instrument should not be suspended from a very light tripod, and I recommend the form that is suspended in a glass case for protecting it against the action of the wind, which materially disturbs its verticality. It might, in some instances, be suspended from the crook of a stout walking stick, which could be firmly stuck into the ground.

In practice a conspicuous object is observed, as part of a rock, stone, or building, which shall be at the judged height of the eye of the observer above the surface of the ground, the distance between one object and another being afterwards measured.

I have the best authority for stating that the tracks of several thousands of miles of railway in Russia were so correctly marked upon the plans from observations taken with this level, that but very trifling deviations were made when a more exact system of levelling was applied to them.

These reflecting levels are of great value for determining the levels of a country on which the dumpy level dare not be taken. In all probability the person employed to warn off the engineer with the dumpy level would not have the slightest idea that a level could be taken with such an instrument as the one suspended on gimbals.

The enclosed form of this level is shown at Fig. 12, the front part of the exterior covering being cut away to show the hanging balance mirror.

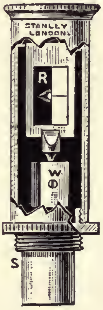

FIG. 12.

CHAPTER III.

The Levelling Staff.

THE levelling staff may be considered, for explanatory purposes, as a strip of wood varying from 10 to 18 feet in length, by about 2½ inches on the face, and figured on the latter in feet and decimals from the bottom upwards.

As it is by the reading of those heights of the staff as they are intersected by the "cross webs" of the telescope of the level (hereafter to be explained) that the system of levelling is performed. it is most important not only to acquire a knowledge of the staff, but to be able to read it quickly. Before attempting to read with a level, it will be well to understand that staves are read through an inverting telescope, and that consequently the reading must be commenced from the apparent top, and continued in an apparent downward direction. The inverting telescope is somewhat troublesome to all beginners, but they soon become accustomed to it, and eventually much prefer it. The object of inverting the image is to secure a clearness of vision that cannot be obtained with an erect eyepiece, the latter having four glasses, and the inverting eyepiece only two. Inversion is so far the rule with eyepieces of scientific telescopes that it is quite rare to find one on the erect principle.

As a rule, the greatest mistake in staff-reading is to read 6 feet for 9 feet, or *vice versa*; but this may be guarded against by having the eye of the figure 9 made solid or otherwise painted for greater distinction.

Figs. 13, 14, and 15 are illustrative of the divisions of levelling staves into feet and decimals, and also of the staves as they would appear when observed with an inverting level—the ground appearing uppermost. Fig. 13

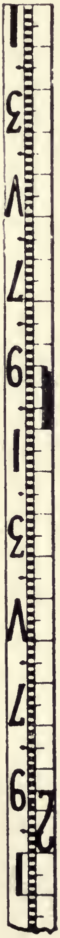

FIG. 13.

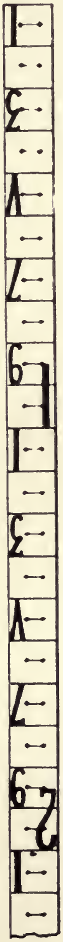

FIG. 14.

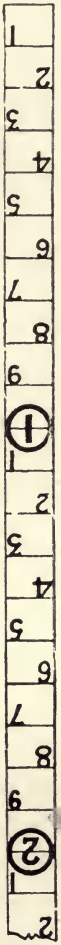

FIG. 15.

is the well-known Sopwith pattern, and is divided to two places of decimals—that is, to the hundredths of a foot.

Figs. 14 and 15 are contrivances of my own.

The pupil cannot do better than confine himself to the Sopwith pattern, which is very easy to read, and clearly defines the hundredth parts; the others he may use when his eye becomes well trained.

It will be observed that one very important character (excepting the large figures in Fig. 15) prevails in these, as in most levelling staves; viz., that the figures are so placed that none of them shall register till they are fully above the line of intersection

Let us take Fig. 13. The large figures on the right hand, indicating feet, do not register till they are intersected quite at their base, or below it; the figures on the left hand, indicating tenths, do not register till they are interescted at their exact base, or below it; and none of the divisions between the tenths, representing hundredths, register till the intersection is quite at their base.

As an example, this staff would register 1.25 feet it if were intersected below the figure 1 on the right-hand side, and quite in the centre of the figure 3, on the left-hand side below the figure 1.

I should say there are probably a dozen arrangements of the figures and divisions of the English levelling staff, beyond the three I have illustrated. The pattern used by the Ordnance Survey Department is a different arrangement altogether. Mr. Rodgers Field and Mr. Stanley have arrangements of their own.

The most convenient staff is the stout mahogany box or telescopic sliding staff* of 14 feet in length which, when losed, is of the same length as the tripod, and can be conveniently packed with it for travelling. Fig. 16 illustrates one of these staves.

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* First introduced by Mr. Gravatt, C.E.

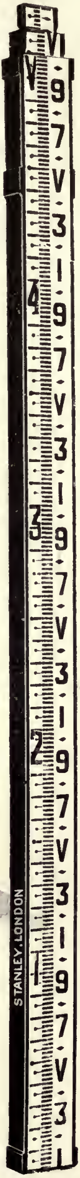

FIG. 16.

Much time may be saved in the field by instructing a pupil to read the staff in the office, erecting it against the wall and intersecting various readings with a piece of black wire.

The staff is generally strapped to the tripod for convenience in travelling, but in all cases its face should be protected against damage. A strip of deal in the form of a straight-edge* placed between the face of the staff and the tripod forms a good protection. A very general plan is to have two pads of thick leather, pierced near the ends to admit of straps passing through them to bind the staff and tripod together in two places, as shown at Fig. 17, or better still, the improved staff and tripod holders shown at Fig. 18.

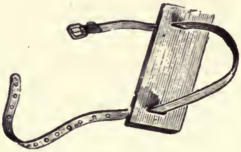

FIG. 17.

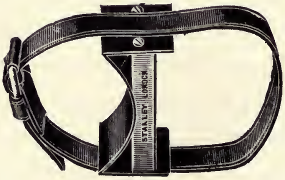

FIG. 18.

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* *Vide* remarks on this head contained in Chap. XIV.

CHAPTER IV.

INTRODUCTION OF THE DUMPY LEVEL—ADVICE TO INTENDING PURCHASERS OF LEVELS — THE ADJUSTMENT OF THE DUMPY LEVEL.

WE will now enter upon the real practice of levelling by introducing the dumpy level on the tripod, disregarding altogether every kind of level in use prior to its invention ; and here we cannot do better than frankly admit the indebtedness of the profession to the late Mr. Gravatt for the conception of those ideas which tended to place in their hands so competent and reliable an instrument.

Fig. 19 is a fair representation of a 12-inch dumpy level and compass on the tripod. The advantages which the dumpy level possesses over all the earlier kinds of levels, are that it has a telescope of much shorter focal length, and a much larger object glass, whereby a sufficiency of light is admitted to allow of a much greater magnifying power in the eyepiece. Nor are these all : it is much more compact, convenient, and rigid than the earlier levels, many of the old movable parts being altogether dispensed with, and much of the instrument that was formerly built up with many members being now in a whole casting. Further, when once in adjustment—and its adjustment is not a difficult matter —it rarely requires readjusting, whereas the adjustment of some of the earlier instruments was almost a daily occupation.

The names of the principal parts of the dumpy level may be gathered from the figure—*A* being the longitudinal or principal bubble tube, *B* capstan adjusting screws to the latter, *C* the small transverse bubble tube and its adjusting screws, *D* the telescope, with good achromatic object glass; *E* the focal adjustment screw, *F* the eyepiece, *G G*, screws for adjusting the diaphragm, *H* the support for compass and telescope in one casting, *I* the compass, *K* the conical axis, terminating in a universal ball and socket joint, *L* the parallel plates, *M* the milled-headed parallel plate screws, and *N* the dew cap or ray shade.

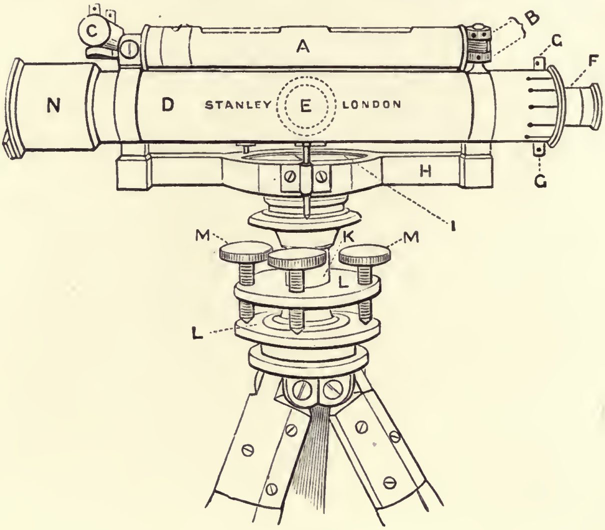

FIG. 19.

A little advice to intending purchasers of levels may here be in the right place.

Avoid, excepting under very special circumstances, the purchase of second-hand instruments ; and shun even the sight of very low-priced new instruments, which are simply trash made for sale and the deception of the unwary, and not for practical use or endurance. Launch out for once in your life, and do not let false economy persuade you to try to save a pound.

Unless you have a professional friend, under whose guidance you can feel quite safe, place yourself in the hands of one of the best known makers of instruments, and be guided by his advice.

For hard wear you require a sound instrument, on gun-metal bearings, having all the modern focal, magnifying, and other improvements. *For home use* a 12-inch level, without compass, is generally preferred ; but for works of considerable magnitude either at home or abroad, a 14-inch one, having a compass, becomes a necessity. There are levels of much larger dimensions, fitted with almost every conceivable kind of unnecessary appendage, that, on account of their weight, can only be borne by a man of great strength, and which are in size utterly out of proportion to the work required of them. If the tripod be of the proper proportions, it does not follow, as has been advocated, that better observations can be made with a heavy level in windy or rough weather than with a light one.

We are undoubtedly indebted to Mr. W. F. Stanley for most of the improvements to be found in modern levels. The introduction of the Iridium reading points to the diaphragm, that altogether supersede both the spider lines, which are often a source of trouble, and always of anxiety to the engineer or surveyor, and the glass stop of Mr. Cushing, which is liable to be obstructive from " dewing," alone makes his instruments the most efficient of any with which I am acquainted, and which I most recommend for hard wear. Words can hardly express the relief an engineer must feel who, every moment anxious for the safety of his spider lines, exchanges them for the strong and permanent points of iridium. Another advantage that these points possess is that they aer far and away the best for stadia reading, as explained in another chapter, in which they are illustrated. The fuller general advantages are the fixed axis, which obviates the error often occasioned by grit getting between the parallel plates and the axis ; a free joint to the principal bubble tube to prevent any strain, which causes distortion ; a prismatic reader to the compass ; the Tribrach construction for levelling, which allows of extremely sensitive bubbles being used such as could not be used in a level on the parallel plate system ; graduation of the bubble tubes to meet the varying lengths of the bubbles from contraction and expansion produced by heat and cold ; a dew cap graduated for the taking of approximate cross sections ; and remarkable rigidity owing to its solid construction and firm connection to a thoroughly good tripod.

Another important advantage possessed by these levels is that the tribrach construction makes the rocking so common to levels constructed on the parallel plate and ball and socket joint system quite impossible. Fig. 20 shows one of these levels ; a further improvement is to fit a clamp and tangent motion to the axis, this obviates any difficulty felt in bringing the points to the reading of the staff exactly.

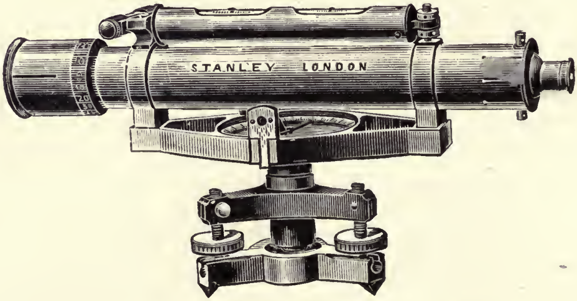

FIG. 20.

It cannot be too strongly emphasized that the fewer the parts, the fewer the adjustments, and the lower and more solidly built the level is, the more accurate it will be, and the longer it will keep in correct adjustment.

The embodiment of these special requirements has recently been introduced by Messrs. W. F. Stanley & Co., Ltd., in their New Engineer's Level, which has revolutionised the form of modern levels ; it is shown at Fig. 21.

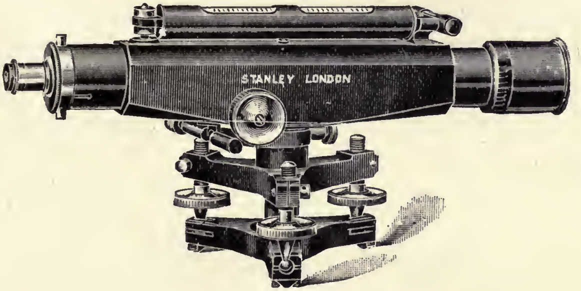

FIG. 21.

In this level the centre is cast in one piece with, and directly upon, the telescope body and object end. The cast telescope body is cored out to a suitable thickness, so that although of vastly greater strength and rigidity, it does not weigh as much as the old form of tubular body, collars and stage, while it does away with many separate pieces which are usually soldered and screwed together, and thus forms the strongest and most compact level yet made, which with ordinary care should last in perfect adjustment a lifetime. The pinion is fitted to the side of the outer cast body, thus adding greatly to its strength. The level is fitted with clamp and tangent adjustment, tribrach levelling, and patent locking plate so that it can be used on a wall or masonry as well as on the tripod.

A further improvement, which will be found to save much time in setting up and save wear of the levelling screws, is a quick-setting lower plate.

It consists of a section of a ball which is screwed to fit the stand top. This ball is clamped within the lower plate and when released allows of sufficient rocking movement in any direction to compensate for the uneven setting up of the stand.

It can be fitted without any alteration to the instrument or its case, it does not add to its height, and with it the instrument may be instantly set nearly level so that less than half a turn of the levelling screws brings it into true position. It is shown fitted to one of the foregoing instruments at Fig. 22.

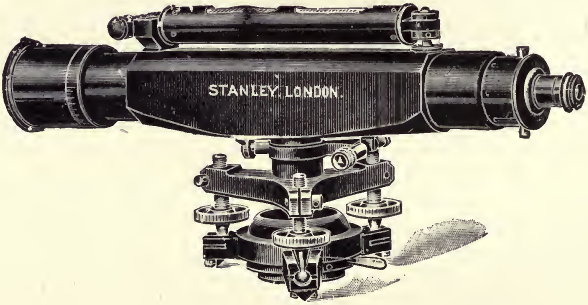
STANLEY. LONDON.

FIG. 22.

As but few surveyors are acquainted with the correct way of measuring a level, and as the measured outer length of the telescope is generally accepted as the nominal size of the instrument, I would here mention that the correct size of a level of any dimension is the length from the inside of the object glass to the diaphragm, or in other words, the solar focus of the object glass.

A very important matter, and one which precedes every kind of adjustment, is a correct setting-up of the instrument; therefore—

To set up the instrument correctly—

Remove the cap from the tripod. Erect the tripod by extending its legs to a convenient distance, and carefully examine it to see that it is quite free from shake, either from want of firm bedding and heading of the wood into the metal, or from looseness of any of the joints or screws. The examination being found in every way satisfactory, press the legs firmly either upon or into the ground, keeping the upper plate as nearly level as it can be kept by the eye, and mount the instrument by firmly screwing it on. Much more importance attaches to the careful examination of the fittings of the tripod than is at first sight apparent; in fact, great inconvenience and annoyance have often arisen from defects due solely to the small amount of care bestowed upon the manufacture and finish of these parts.

The adjustments of the dumpy level may be classified under three headings, viz.:—

1. The adjustment of the principal bubble tube *A*, which, when properly performed, causes the bubble to stand in the centre of its run when the axis of the instrument is vertical, and to retain the same position during an entire slow revolution of the telescope on its axis.

2. The complete focal adjustment of the telescope and elimination of parallax.

3. The adjustment of the line of collimation by making it truly parallel to the bubble tube and likewise rectangular to the vertical axis of the instrument.

To adjust the principal bubble tube A, if four screw levelling. With four screw levels, some are fixed to the stage and some are made to unscrew for portability. They are much better fixed, as the saving in portability is very little, and the risk of displacement of a detachable centre is great ; and great care should always be taken with them to see that the faces that screw together are perfectly clean, as the least piece of grit will cause displacement.

The tripod stand being set up as described, the parallel plates, if separate, are taken from the case and screwed firmly, but not too tightly, upon it. The instrument is then taken from the case and screwed firmly to the centre, or, when it has the centre fixed, the whole instrument is taken from its case and screwed firmly upon its stand. The eyepiece is then focussed as described further on, the ray-shade drawn, and the telescope roughly focussed upon some distant object, then the telescope is brought truly over a pair of the parallel plate screws, *M*—a pair being two which are in a straight line with the axis of the instrument —the milled heads of the pair of screws are seized with the forefingers and thumbs of each hand and turned *together* in opposite directions, by a wrist motion to the left or right, as occasion may require, till the bubble becomes *approximately* near to the centre of its run ; the telescope is then brought over the other pair of screws and the like operation is performed. The telescope is then again placed over the first pair of screws, and by turning them the bubble is brought quite to the centre of its run, and the telescope reversed to see if it will retain its central position.

If the bubble be found not to retain its central position, the telescope is brought over the other pair of screws, and by turning them brought it to the centre of its run, and the telescope again reversed.

If a three-screw levelling or tribrach instrument, place the telescope in line with any two levelling screws and bring the bubble to the centre of its run, then place the telescope at right angles to this, and the other levelling screw comes under the telescope ; bring the bubble to the centre of its run, now return to the first position to see that this is right. If not exact, repeat the operation. If the bubble will not retain its central position, the bubble tube is out of adjustment, *i.e.*, is not at right angles to the vertical axis of the instrument, but care should be taken before altering its adjustment in any way, to be sure that it is the bubble that is out of adjustment, and not want of care in setting the instrument up level.

The bubble is handier to work with when adjusted to reverse in the centre of its run, but it does not really matter, as equally accurate work can be done with it in any other position. Should it not reverse in the centre of its run, adjust the instrument by the levelling screws until it reverses in some position. Say you start with the bubble in the centre and on reversing it, it runs towards the eye end of the telescope 6 divisions, then alter the levelling screws until it is only half this, or 3 divisions, and it will then reverse with the bubble three divisions towards the eye end, and if properly levelled, the telescope will make an entire revolution with the bubble in that position, which will prove that the axis is vertical. The bubble can now be adjusted by the opposing nuts at the one end by means of the tommy pin (provided in the case) until it is in the centre of its run, and it will then reverse in that position, instead of three divisions towards the eye end.

Throughout this operation, if a four screw level, it is of the utmost importance that the screws *M* shall be turned to an approximate uniformity of moderate pressure upon the plate ; in other words, so that the tightness of the one pair shall not be much in excess of the tightness of the other, as the power that irregularly tight screwing will impart to them upon the centre, through the parallel plate, will be fully enough to deform the axis to an extent that will affect the run of a bubble that is as sensitive as it should be.* It is, however, equally important to see that each screw has an actual and independent pressure on the lower plate, or the instrument will rock on the ball and socket joint.

If the instrument cannot be thus made to reverse or revolve, its axis is at fault, and it can only be remedied by the maker—unless perchance the bubble be too sensitive for the parallel plate system of construction.

A matter of this kind is much more easy of description or illustration than of manipulation ; and it would not be surprising to find that, before completing the adjustment of the principal bubble tube, the student should be obliged to return several times to the adjusting screws *B*.

To adjust the focus of the telescope and destroy the effects of parallax.

When the telescope is in focal adjustment, the image of an object formed at its focus will exactly coincide with the point in the telescope at which the image is observed, and this point in the telescope of a level is determined by the position of the " cross webs " of the diaphragm, upon which

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* Levels constructed on the " tribrach " system admit of much more sensitive bubbles than can be applied to those on the parallel plate system.

I shall treat hereafter. If the image fall either short of or beyond this point, there exists an error of adjustment called *parallax.*

If the image fall short of the point—*i.e.* it if be on that side of the point which is towards the object glass—the error is known as *far* parallax; but if on that side which is towards the eyepiece, it is called *near* parallax. To determine if any parallax exist, and likewise to correct it, draw out the eyepiece *F* to such a length as may be necessary to clearly define the "cross webs"; erect the levelling staff at any convenient distance, say 15 yards from the level, and by turning the focal adjustment screw *E*, adjust the focus so as to sharply define the most minute reading of the staff. Now, assuming the instrument to have a good eyepiece, and that the eye on Fig. 15 were moved slowly up and down between the points *P* and *Q*, and that the "cross webs" during the entire movement remained clearly defined on one exact point of the staff, there would be no parallax; but if the motion of the eye produced an apparent motion or wavering of the cross webs—but which in reality would be a movement of the image of the object observed—there would be an error of parallax. Further, if the motion corresponded exactly with the motion

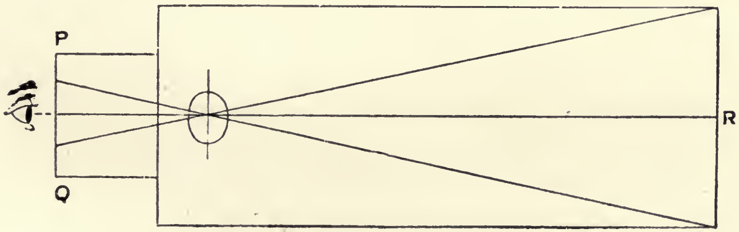

FIG. 23.

of the eye, the error would be one of *far* parallax; and if exactly reverse to the motion of the eye, *near* parallax.

To correct the error of parallax, slightly move the object-glass by the focal adjustment screw *E* till you have its correct focus. To prevent confusion from the sighting of objects, it is better to hold a piece of paper in front of the object glass or to throw a handkerchief over it, to obtain a soft light. The eyepiece being in correct focus the paper or handkerchief is removed and the object glass is racked out by the focussing milled head E until the desired object is in exact focus.

You will thus establish a true coincidence between the image of the object and the point in the telescope at which the image is observed. In Fig. 23, *R* is the object-glass end of the telescope, and *O* the point of coincidence.

When the eyepiece is correctly set, it will remain so unless it should be moved by accident, but at every change of distance the length between the point *O* and the object glass *R* will have to be increased or shortened to the requisite focal length by turning the focal adjustment screw *E*.

It may be here remarked that the hat of the observer should, as a matter of necessity, be kept well to the back of the head to prevent the brim of it from coming into contact with the level.

To adjust the line of collimation.

The adjustment of the line of collimation is by far the most important adjustment of the level; particularly important, because an error in its adjustment, unlike the errors already explained, is quite invisible, and can only be discovered by a practical test.

When the line of collimation, which is no other than the line of observation through the telescope, is quite parallel to the bubble tube, and at right angles to the vertical axis of the instrument, it is in adjustment; but how are we to know whether it is in adjustment or not? and if out of adjustment, how are we to correct the error?

Of the several schemes that have been devised for this test and correction, the following recommend themselves as simple and exhaustive.

Select a piece of tolerably level ground (*vide* Fig. 24), and set up and level the instrument exactly over the point *A*, and at *B* and *C*, being points equidistant—say 20 yards—from *A*, drive stakes having squarely cut tops to within a few inches of the ground, and note the readings of the staff when held on the tops of them. This done, and the readings being respectively on *B* 4.50 feet, and on *C* 4.75 feet, lower the stake *B* 0.25 feet, or 3 inches, to make the readings exactly alike.

Reference to the figure will clearly show that inasmuch as the readings at *B* and *C* are alike, the tops of the stakes must of necessity be on the same level, no matter how great the error of collimation, because both points being equidistant from the point of observation, the error is balanced. The line *x*————*x* in the figure shows the line of collimation

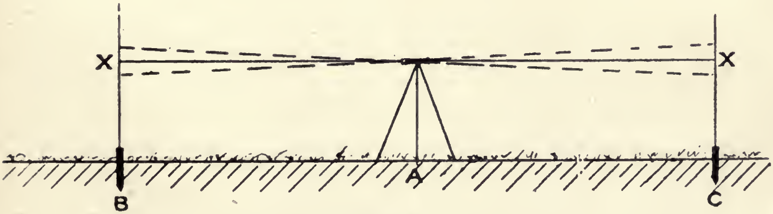

FIG. 24.

in adjustment. The dotted lines above and below it show the lines of error.

Being satisfied that the tops of the stakes are upon the same level, set up the instrument about* 10 feet to the side or rear of stake *C*, and read the staff on the top of it, which we will presume shall be 4.60 feet. Now read the staff on the top of the stake *B* from the same point of observation, when if the line of collimation be in adjustment, the reading will be the same as at *C*, viz., 4.60 feet. Should, however, the reading at *B* be 4.75 feet, the diaphragm slide which carries the " cross webs " must be raised by means of the adjusting screws *G* (Fig. 19) till the reading of the staff on both stakes is the same.

Again, the bubble tube being accurately set, read the staff on equidistant stakes driven into the ground at any convenient level, and note the difference between the readings, which will be the correct difference of level, no matter whether there be an error of collimation or not.

As an instance, suppose the instrument to be erected, as in the former example, midway between the staff-holdings, but the stakes not driven in until they read an equal height, and the staff-reading at *B* to be 5.50, and at *C* 2.45, the difference, which would be the correct difference of level would be 3.05. Now set up and level the instrument as close to *B* as to be able to read the staff when held on the stake, which we will presume shall give a reading of 5.00, then the reading on the staff held at *C* should be 5.00 feet, less 3.05 feet=1.95 feet if the collimation be correct. If not the adjusting screws of the diaphragm should be altered till staff at *C* reads a difference of 3.05 feet from staff at *B*.

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* A less distance if the telescope can be focussed for it.

I prefer the former scheme as being in every way the least complicated; without care in the latter the surveyor might mistake a rise for a fall, and thus put the instrument most seriously *out* of adjustment.

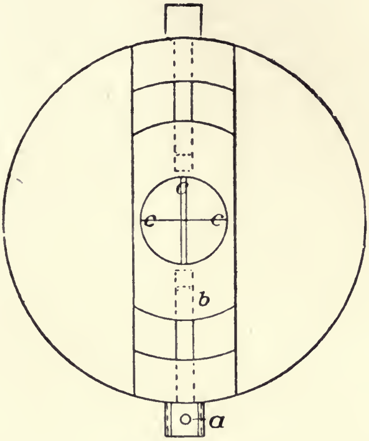

FIG. 25.

Fig. 25 is illustrative of the diaphragm already referred to—*a a* being the adjustment screws, as shown at *G G* (Fig. 19), also called by some the collimation screws—*b* the slide of the diaphragm which carries the cross webs, and *c c c* the cross webs. The latter are termed "cross webs" simply because they cross each other at right angles, the horizontal web being the one which bisects the staff at the point of level, the vertical ones being to test the verticality of the staff held by the assistant.

An assistant holding a staff should at all times stand behind it with his face towards the observer.

The student must be very particular, at the completion of this adjustment, to see that *both* the adjusting screws of the diaphragm have a firm bed on the outer surface of the telescope.

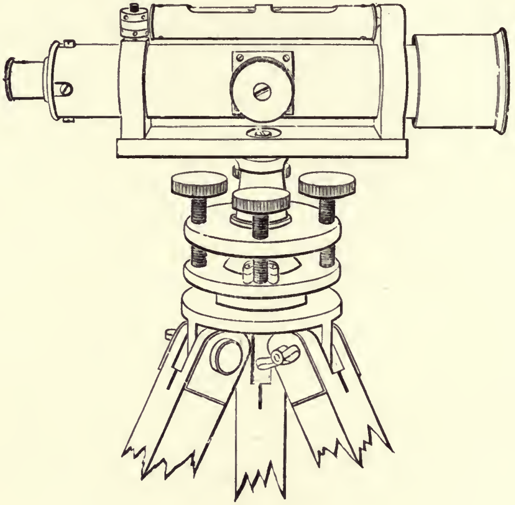

FIG. 26.

Our attention has recently been directed to the dumpy level, illustrated by Fig. 26. This instrument, which embodies the principal essentials of the larger level illustrated by Fig. 19, is a very reliable one for the general work of a builder, contractor, or drainage foreman. Mr. Stanley makes a very good level slightly varied from this model for the low sum of £4 10 0. The actual instrument illustrated is £7 10 0.

CHAPTER V.

REFRACTION—DETERMINATION OF A LEVEL FROM A SINGLE OBSERVATION—DETERMINATION OF A LEVEL FROM A SERIES OF OBSERVATIONS, TOGETHER WITH A FORM OF FIELD BOOK.

IN determining the correct level of a distant object from a single observation—the level of course being in adjustment to an infinitesimal degree of nicety—we have the value of two very important factors to take into account; one being the curvature of the earth, as already explained in Chap. I.; the other terrestrial refraction. Terrestrial refraction, or for our purposes simply *refraction,* is produced by the bending of the rays of light from the object observed towards the point of observation, and its effect is to deceive the observer by making any object observed by him appear at a greater altitude than it really is. This bending is produced by the passing of the rays of light through the atmosphere, which gradually increases in density as it approaches the earth; and as the density becomes gradually greater and greater the path of the ray of light becomes gradually depressed more and more until it takes the form of a curvilinear track, which upon entering the object glass of a level may be considered to terminate and be left tangential to the line of collimation. The true form of the refracted ray of light, owing to the variety of atmospheric disturbances, is most difficult to determine; but those of our scientific men who have taken the matter in hand have decided that for all practical geodetic operations it may be regarded as one-seventh part of the allowance to be made in respect of the curvature of the earth, from which it must be deducted, as will be seen on reference to Fig. 27—*a* being the true position of the object observed, *b* its apparent position, *c d* and *c e* parallels drawn to account for the height of the instrument above the surface of the ground, and *d f* the allowance to be made in respect of the curvature of the earth, of which *d e* is a seventh part.

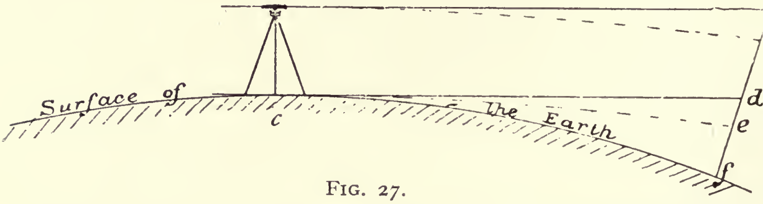

FIG. 27.

Now the curvature of the earth produces an apparent *depression* of an object viewed, as will be made quite clear from the following example, and from reference to Fig. 28.

The level being properly set up, as shown in the figure, the centre of the eyepiece being 4.75 feet above the ground, and the horizontal cross web reading on the summit of a chimney at a distance of four miles, required the difference of level between the site of the observation and the summit of the chimney.

	Feet.
Curvature for 4 miles (*vide* Chap. I.) = .667 feet × 16 =	10.672
Less one-seventh for refraction	1.524
	9.148
Add for height of the instrument	4.750
Difference of level	13.898 feet.

It will thus be seen that the summit of the chimney is 13.89 feet higher than the site of the observation.

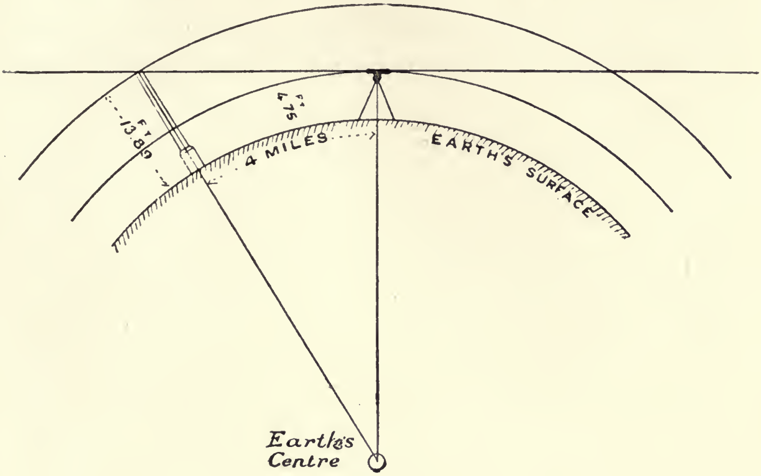

FIG. 28.

Refraction, like curvature—as already explained in Chap. I. —is seldom taken into account in ordinary practice. During my long experience as a surveyor, I have never once found it necessary to take the curvature of the earth, and refraction, into consideration.

The general method of obtaining the difference in level between two given points on a piece of land that may not exceed seven or eight chains in length, and has not upon it a rise or fall of more than about 9 feet, is to erect the level midway between the points, and to take a staff reading on each of them, calling the reading registered by the first observation a *back sight*, and the reading taken by the second a *fore sight*, and to deduct the lesser reading from the greater, when the difference will be the difference in level. The result thus obtained is reliable to the greatest degree of accuracy, and is obtained regardless of the consideration of either curvature or refraction; in fact, as reference to Fig. 24 will show, the result would be correct even if the line of collimation were out of adjustment—a contingency not to be calculated upon hereafter. The cases in which such allowances as have been described *may* be necessary are the checking of long levels over extensive flat country for railway or canal work.

It more frequently, however, happens that when the difference of level between two given points is required, such points are at some great distance from, and invisible to, each other; in consequence of which the difference of level cannot be determined by either a single or double observation. In such cases it is necessary to take continuous observations, and these are described in the treatment of the following example, of which Fig. 29 is an illustration. Required the difference of level between the points *a* and *g*

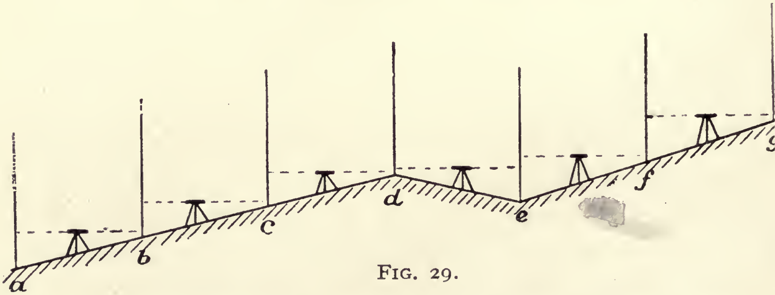

FIG. 29.

(Fig. 29), such points being invisible from each other, and about, say, 24 chains apart.

Now, as will be seen on reference to the figure, the staff is held, as nearly as can be judged by the eye, at two chains on each side of the instrument. This distance, where the configuration of the earth will admit of it, is a very convenient one, and at which the smallest divisions of the staff can be distinctly read. We will return to the example. Rule a field book* in the following form:—

Rise.	Back Sight.	Fore Sight.	Fall.
6.00	7.50	1.50	...
5.45	6.35	0.90	...
5.75	6.20	0.45	...
...	1.11	4.11	3.00
7.01	7.10	0.09	...
7.00	8.01	1.01	...
31.21	36.27	8.06	3.00
3.00	8.06		
28.21	28.21		

Which being done, erect the instrument as nearly as can be judged about two chains from *a* in the direction of *b*, read the staff on *a* as a *back* sight, and enter the reading as a back sight under the proper heading of the book; then reverse the telescope, and read the staff at *b* as a *fore* sight, and enter the reading as a *fore* sight under the heading of "Fore Sight." Now instruct the staff-holder to maintain his exact position at *b*, simply reversing the face of the staff, and remove the instrument about two chains from *b* in the direction of *c*, read the staff on *b* as a *back* sight, and enter the reading as a *back* sight; then reverse the telescope, and read the staff on *c* as a *fore* sight, and enter the reading as a *fore* sight. Then instruct the staff-holder to maintain his exact position at *c*, remove the instrument about two chains from *c* in the direction of *d*, and proceed after this manner by continuous back and fore sights on *d*, *e*, and *f*, until the last *fore* sight is on the point *g*.

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*Field books suitably ruled, with printed headings, can be purchased at the instrument makers'.

It will be observed that in this example there are six double observations, and consequently six lines of back and fore sights in the field book; therefore, as has already been shown, the difference between one back sight and one fore sight is the difference in level between the two points covered by the two sights, it will only be necessary to add up the columns of back and fore sights, and deduct the lesser sum from the greater for the difference of level. This field book is so arranged as to show that whenever the back sight is greater than the fore sight there is a rise, and that whenever the fore sight is greater than the back sight there is a fall; it is also so arranged that the deduction for rise or fall in respect of each observation shall be placed in that column which is side by side with the greater of the two sights. This arrangement on the one hand tends to facilitate matters and obviate error, and on the other affords a proof of accuracy. To prove the accuracy of the figures of the field book, we deduct, as shown, the difference between the rise and fall in respect of each observation, and add up the four columns, when the difference between the totals of the back and fore sights should be equal to the difference of the totals under the headings " Rise " and " Fall."

In the present example there is a rise from *a* to *g* of 28.21 feet; but it is absolutely necessary that this should be proved to be a correct determination. The proof is simple; it consists of an entire reversal of the operation by commencing at *g* and levelling to *a*, when, if everything be correct, the fall determined from *g* to *a* will be equal to the rise from *a* to *g*. The levels taken for proofs of this kind are termed running or check levels.

CHAPTER VI.

THE DATUM EXPLAINED—EXPLANATION OF THE TERM "BENCH MARK"—LEVELS TAKEN AND A SECTION MADE ON A GIVEN LINE.

WE now enter upon levelling as applied to the preparation of sections, first explaining that a section is a representation, drawn truly on paper to a scale, of such a profile of the earth's exterior as would be visible were the earth divided into two halves, as an orange is often divided with a knife; in other words, it is a drawing, to a scale, made to show the naturally undulating character of the earth's surface on a given line of route. But to complete a section for this purpose as a working drawing, it is necessary to show, both by scale and by figures, the comparative heights of all the elevations and depressions of the surface from a common line of horizontality, which is a line drawn concentric to the earth's mean exterior, and at such a distance nearer its centre as circumstances may determine to be convenient. This line is termed the "Datum" line, and for convenience in drawing and in making subsequent calculations, notwithstanding that it partakes of the form of a curve, it is shown on paper as a perfectly *straight* line.

Now the smallest amount of consideration will show us that a section cannot be drawn to a scale without the determination of the horizontal distances between the several points of vertical observation, and these distances should be measured with a chain, or as a *continuous measurement* from the point of their commencement.

Fig. 30 is a plan, drawn at a scale of 8 chains to an inch, of a property through which it is desired that a section shall be taken, commencing at the point marked *A*, and, following the course of the dotted line, terminating at the point marked *B*. On this plan, for the better elucidation of the system to be pursued, and for the easier tracing of the operations in their order of progression, I have on one side of the dotted line figured the horizontal distances in chains and decimals, and on the other side placed the letters *a*, *b*, *c*, *d*, etc., opposite the several points of distance, which will be found to correspond with letters placed alongside such back and fore sights in the field book as are taken on the points so lettered.

On the section the letters are again repeated for simple reference, and, to make matters still more clear, the several settings up of the instrument are shown, together with the nature and number of the sights taken from each point of observation. At either end of the line *A B* on the plan will be noticed the letters B.M.: these stand for bench mark. This being a horizontal mark or cut* on a post, wall, dwelling-house, or other structure, or a noted angle or point in a structure on which the exact position of a level can be defined and left for future reference. Bench marks should always be left on long lines of sections at intervals of about 20 chains,† so that in case of the accidental

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* The bench marks used by the Ordnance Survey Department are marked thus: ⊼

† Differences of opinion exist as to this distance; the beginner, however, cannot do better than leave them at short intervals, using his own judgment later on.

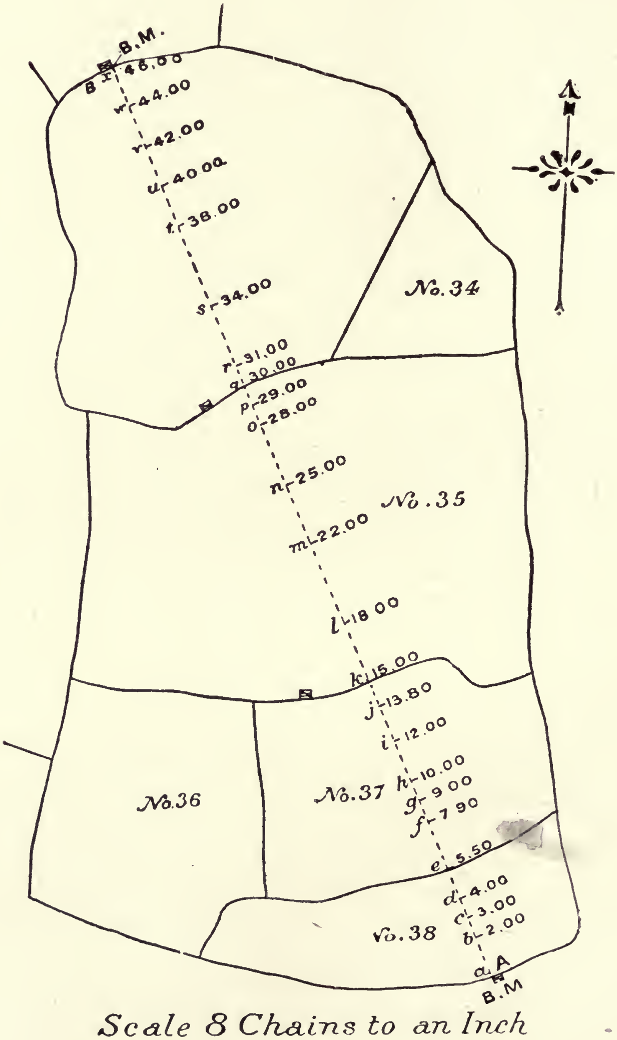
B.M.
B
x 46.00
w 44.00
v 42.00
u 40.00
t 38.00
s 34.00
r 31.00
q 30.00
p 29.00
o 28.00
n 25.00
m 22.00
l 18 00
k 15.00
j 13.80
i 12.00
h 10.00
g 9 00
f 7 90
e 5.50
d 4.00
c 3.00
b 2.00
a A
B.M
No. 34
No. 35
No. 36
No. 37
No. 38
Scale 8 Chains to an Inch

FIG. 30.

removal of the staff, or a sudden discontinuation of the work on account of the weather or otherwise, a return may be made to the last bench mark, and the work at once resumed therefrom.

The field book being ruled in the following form, we will commence the operations necessary to the production of the section. Set out the straight line *A B* on the land by means of ranging poles or light "papers,"* unless it be naturally defined, and measure it from the point *A* to the point *B*, carefully noting this in the field book, in the column headed "Horizontal Distance," of the reading of the chain as it lies upon every turn of gradient of the surface, and at every crossing of a fence (always leave three blank lines at the top of the field book). Mark the ground with a small spade, or by pegs carried by the chainman, so that the several points of measurement shall be easy of after identification.

Now write on the blank lines at the top of the field book, "Datum——————B.M. cut on gate-post," the blank between the word Datum and B.M. being filled in at the completion of the levelling, conformably to the matter of convenience hereinafter referred to. Commence the levelling by setting up the instrument four or five yards out of the line of section, and opposite the point *b*, and take a back sight on the B.M.; then take as fore sights readings of the staff on *a*, *b*, *c*, and *d*, without moving the instrument, and instruct the staff-holder to maintain his exact position at *d*, simply reversing the face of the staff. Now erect the instrument about mid-way between *d* and *f*, and take a back sight on *d* and a fore sight on *f*, directing the staff-holder to

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* *Vide* "The Practical Surveyor," by the author.

FIELD BOOK TO FIG. 30

Rise	Back Sight.	Fore Sight.	Fall.	Reduced Levels	Horizontal Distance.	Remarks.
					Chains.	
...	...	...	...	20.00	Datum.	20 feet below B.M. cut on gate-post
...	B.M. 5.50	*a.* 6.00	0.50	19.50	0.00	Level of land at above B.M.
2.50	*a.* 6.00	*b.* 3.50	...	22.00	2.00	
...	*b.* 3.50	*c.* 4.20	0.70	21.30	3.00	
0.70	*c.* 4.20	*d.* 3.50	...	22.00	4.00	
...	...	...	...	...	5.50	Crosses fence between Nos. 37 and 38.
2.00	*d.* 4.05	*f.* 2.05	...	24.00	7.90	
...	*f.* 4.50	*g.* 5.50	1.00	23.00	9.00	
1.50	*g.* 5.50	*h.* 4.00	...	24.50	10.00	
2.50	*h.* 4.00	*i.* 1.50	...	27.00	12.00	
2.50	*i.* 5.30	*j.* 2.80	...	29.50	13.80	
...	...	...	...	...	15.00	Crosses fence between Nos. 35 and 37.
...	*j.* 2.80	*l.* 3.30	0.50	29.00	18.00	
...	*l.* 2.70	*m.* 4.70	2.00	27.00	22.00	
0.80	*m.* 5.40	*n.* 4.60	...	27.80	25.00	
4.50	*n.* 4.60	*o.* 0.10	...	32.30	28.00	
0.70	*o.* 5.60	*p.* 4.90	...	33.00	29.00	
...	...	...	...	...	30.00	Crosses fence between Nos. 33 and 35.
1.20	*p.* 4.90	*r.* 3.70	...	34.20	31.00	
0.25	*r.* 3.70	*s.* 3.45	...	34.45	34.00	
2.55	*s.* 5.00	*t.* 2.45	...	37.00	38.00	
...	*t.* 3.90	*u.* 4.40	0.50	36.50	40.00	
2.50	*u.* 4.40	*v.* 1.90	...	39.00	42.00	
1.52	*v.* 5.75	*w.* 4.23	...	40.52	44.00	
0.48	*w.* 4.23	*x.* 3.75	...	41.00	46.00	
0.50	*x.* 3.75	B.M. 3.25	...	41.50	46.00	B.M. cut on gate-post.
26.70	99.28	77.78	5.20			
5.20	77.78					
21.50	21.50			21.50	taken from last reduced level.	
				20.00	= Datum level.	

maintain, as heretofore, his exact position on the latter point of forward observation. Next set up the instrument alongside the point *h*, and take a back sight on *f*, and fore sights on *g*, *h*, and *i*, and so on as illustrated by the section (Fig. 31), and the letters in the field book, until the levelling terminates in a fore sight on the B.M. on the gate-post at *B*.

Now, without regard to horizontal measurements, level from *B* to *A* by means of the system of running levels described in the last chapter, to test the accuracy of the work.

If the pupil has carefully followed me, his attention must have been arrested by the blanks in his field book, which are occupied in mine by the back sights *a*, *b*, *c*, *g*, *h*, *j*, *n*, *p*, *r*, *u*, *w*, and *x*; and these I now propose to account for.

It will be observed that, previous to this chapter, we have only touched upon levelling either by direct single or double observation; but that in the levelling now before us we have at one setting up of the instrument taken many observations. As an instance let us revert to the five observations taken from one setting up of the instrument alongside the point *b*; the first observation was a back sight of 5.50 taken on the bench mark; the second a fore sight of 6.00 taken on the ground at *a*; the third a fore sight on *b*; the fourth a fore sight on *c*; and the fifth a fore sight on *d*. Now, inasmuch as the difference between a back and fore sight has already been accepted by us as the difference of level between two observations, it only remains that we shall reproduce the fore sights *a*, *b*, and *c* in the form of back sights on the lines immediately below them; in other words, that we imagine we had erected the level for a double observation only between *a* and *b*, *b* and *c*, and *c* and *d*, and that the back sights, by some peculiar run of circumstances, were exactly coincident with the existing intermediate fore sights.

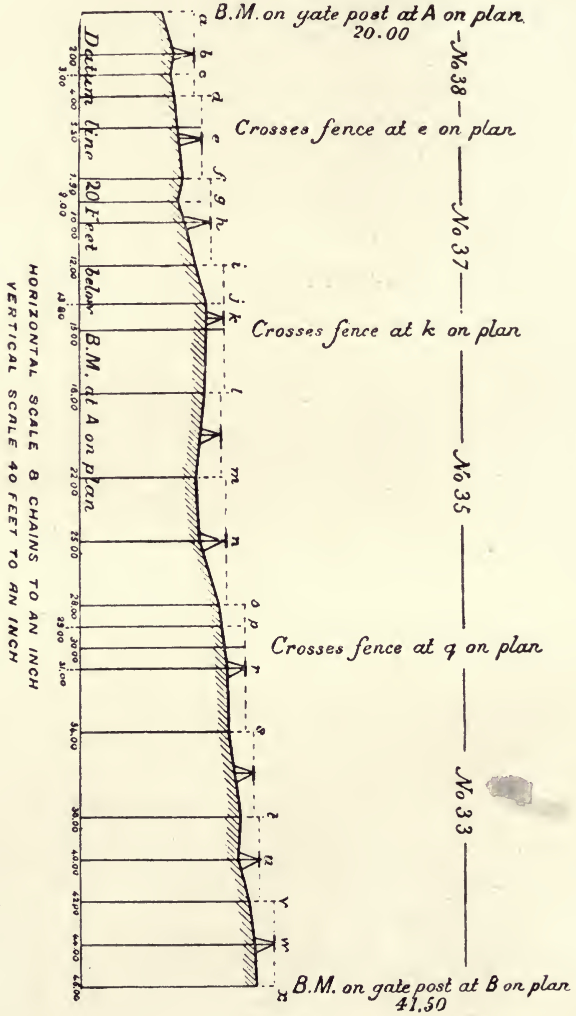
B.M. on gate post at A on plan.
20.00
Crosses fence at e on plan
Crosses fence at k on plan
Crosses fence at q on plan
B.M. on gate post at B on plan
41.50
No 38
No 37
No 35
No 33
Datum line 20 Feet below B.M. at A on plan
HORIZONTAL SCALE 8 CHAINS TO AN INCH
VERTICAL SCALE 40 FEET TO AN INCH
a
b
c
d
e
f
g
h
i
j
k
l
m
n
o
p
r
s
t
u
v
w
x
2.00
3.00
4.00
5.50
7.90
9.00
10.00
12.00
13.80
15.00
18.00
22.00
25.00
28.00
29.00
30.00
31.00
34.00
38.00
40.00
42.00
44.00
46.00

FIG. 31.

I may now remark that when the country is very undulating and rugged, there need be no limit to the number of observations to be taken from one setting up of the instrument.

The field book being complete as far as back and fore sights are concerned, the deductions made in respect of rise and fall, the columns cast up, and the rise of 21.50 feet determined, let us assume a datum. Now, as will be seen on reference to the section, about 20 feet will be a convenient height for the lowest point of the surface level to be above the datum line. We will therefore assume 20* feet, and enter it as shown in the field book in the blank after the word "datum." This entry made, and 20.00 feet entered at the top of the column headed "Reduced Levels," deduct the fall of 0.50 feet from the 20.00 feet for the reduced level of the land at the commencement of the section; then add the rise of 2.50 feet to the last reduced level for the reduced level at 2.00 chains; and so continue to deduct each fall from the immediately preceding reduced level, and add each rise to the reduced level immediately before it throughout the column, when, as a result, you will have the comparative levels from the same datum opposite to the points of horizontal measurement to which they refer.

The field book being now in every way complete, let us enter into the preparation of the section.

The smallest amount of consideration will show that, by reason of the vast disproportions of length and height, it would be impracticable to draw a section of any considerable portion of the earth's surface—so that the vertical measurements should be distinctly readable—at one uniform scale. We therefore employ such a scale of horizontality as we may consider to be convenient, and a very much more magnified scale for verticality. The scales employed in this section (Fig. 31) are such as are adapted to the size of the page—it being my intention to avoid larger illustrations—but, generally speaking, a horizontal scale of 2 chains to an inch, and a vertical scale of 10 or 20 feet to an inch, will be found very suitable. Much, however, as to scale must depend upon the exigencies of the moment; for instance, in certain cases it might be advisable to employ a vertical scale of 8 feet to the inch, which would be the scale represented by the ordinary divisions on a carpenter's rule.

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*Any other assumed datum beyond 20 feet would answer equally well: the determination is hinged on convenience.

The preparation of the section presents little or no difficulty, the *modus operandi* being as follows:—On a suitable sheet of drawing paper rule the datum line in pencil, and prick off and figure all the horizontal distances; rule all the rectangular vertical lines to beyond the height of their actual requirement in pencil, assisted by either a straight-edge and set square, or a T square and drawing board; write as shown on the section (Fig. 31) all the vertical heights, prick off the same, and draw the surface line perfectly straight from one pricker hole to another. Finally, ink in the section, adding anything by way of remark that may suggest itself as a useful addition, or to be employed for the purpose of identifying the section with the plan, or with any part of the land.

CHAPTER VII.

REMARKS ON SOME OF THE MATTER OF THE PRECEDING CHAPTER—COLLIMATION METHOD OF LEVELLING—IMPORTANCE OF TRUE HORIZONTAL MEASUREMENT—ON STAFF-HOLDING.

ALTHOUGH, for purposes of easy illustration, I have, in the foregoing field book, reproduced the intermediate fore sights as back sights at the completion of the levelling, it is far better that they should take their places as back sights as the work proceeds. If, however, we adopt the following form of field book (Fig. 32), which can be compared with the foregoing one, and which finds favour with many surveyors, and keep a separate column for the intermediate sights, we shall have no reproduction or repetition of figures.

I will at once say that the latter form of field book has no charm for me, unless I may accept as such the exemplification of the minor importance of the intermediate sights.

Mr. W. H. Wells, C.E., of the Bengal Public Works Department, who is unquestionably a good authority upon levelling, states in his paper on this subject: "The old form of level field book giving six columns for readings of the level heights on the staff, and their reduction for plotting purposes, viz., back, intermediate, and fore sight, rise, fall, and reduced level columns, is unnecessarily long and tedious to make up in any case. I therefore recommend the system of keeping the readings of the level heights in one column, which is already done by many engineers, though the system is not generally known and adopted; the reduction of the levels is a much simpler process than from the old form of level field book, and I have found it, after several years' use, no more liable to lead to mistakes in noting down the readings than the old form of book. I give an example of it here for those who may be unacquainted with this simple system of level field book.

Back Sight.	Intermediate Sight.	Fore Sight.	Rise.	Fall	Reduced Levels.	Horizontal Distance. Chains
					20.00	Datum
5.50	6.00	...	...	0.50	19.50	0.00
...	3.50	...	2.50	...	22.00	2.00
...	4.20	...	...	0.70	21.30	3.00
...	...	3.50	0.70	...	22.00	4.00
4.05	...	2.05	2.00	...	24.00	7.90
4.50	5.50	...	...	1.00	23.00	9.00
...	4.00	...	1.50	...	24.50	10.00
...	...	1.50	2.50	...	27.00	12.00
5.30	2.80	...	2.50	...	29.50	13.80
...	...	3.30	...	0.50	29.00	18.00
2.70	...	4.70	...	2.00	27.00	22.00
5.40	4.60	...	0.80	...	27.80	25.00
...	...	0.10	4.50	...	32.30	28.00
5.60	4.90	...	0.70	...	33.00	29.00
...	3.70	...	1.20	...	34.20	31.00
...	...	3.45	0.25	...	34.45	34.00
5.00	...	2.45	2.55	...	37.00	38.00
3.90	4.40	...	...	0.50	36.50	40.00
...	...	1.90	2.50	...	39.00	42.00
5.75	4.23	...	1.52	...	40.52	44.00
...	3.75	...	0.48	...	41.00	46.00
...	...	3.25	0.50	...	41.50	46.00
47.70		26.20	26.70	5.20		
26.20			5.20		21.50	
21.50			21.50		20.00	datum

FIG. 32.

"It will be seen from this specimen that the readings, whether back, intermediate, or fore, are all entered in one column alongside the distances. It is only necessary to draw a line under the last fore sight every time the instrument is moved to take a back sight at the same place. As there are two opportunities given to the surveyor of drawing this line, namely, when taking the fore sight, or the next back sight, after altering the position of his instrument, it is almost impossible for him to miss drawing this line at the right place; and if a surveyor were careless enough to do this, he would be just as likely to make an equally fatal error in the old system of level field book. The reduction of the levels for plotting is most simple, and will be understood by reference to the above specimen of field book. To check the figures of the reduced levels, all that is necessary is to add all the back sights together, also all the fore sights, and

Distance.	Level Readings.	Reduced Levels.	
...	...	101.00	Datum + first back sight, from which all level readings are to be deducted up to the back sight.
0	1.00	100.00	Datum for plotting.
30	6.20	94.80	
100	9.50	91.50	
300	2.30	98.70	
Back sight.	4.50	103.20	Not to be plotted. Last reduced level + new back sight to be used as new basis for calculation.
50	2.00	101.20	
100	7.50	95.70	
300	9.40	93.80	

subtract one from the other, and their difference should agree with the difference of the first and last reduced level of the points surveyed. For instance, in the above field book there are:—

Two back sights, 1.00 + 4.50 = 5.50
Two fore sights, 2.30 + 9.40 = 11.70

Difference = 6.20
First reduced level at 0 = 100.00
Last ,, ,, 300 = 93.80

Difference = 6.20

"The simplicity and neatness of this system is evident and I think it only requires to be more generally known to be used in place of the lengthy system of level field book generally taught in works on surveying, and which, I believe, is more often adopted than the simple system above described."

We are all prone to fancy that the method of procedure to which we have accustomed ourselves is the best; correctly speaking, however, there is *something* to be said in favour of almost every method. Mr. Wells recommends his own, which certainly is an ingenious one; I prefer the one to which I have so long been accustomed, although I dare not say it is the better of the two.

Collimation Levelling or Height of Instrument Method.—This is merely a different system of recording the field levels and saves one column of figures in the field-book, the columns for "rise" and "fall" not being required; they are replaced by a single column known as the Collimation level or height of instrument, and the reduced levels are obtained by subtracting the intermediate and fore sights from the height of the line of collimation generally called the height of instrument. The system eliminates the chance of error in booking a rise in the fall column, or *vice versa,* but the chief advantage is the ease and rapidity with which the reduced levels can be deduced in the field, as the reduced level is known directly the staff reading on the station is recorded.

The height of instrument has no reference to setting up the instrument at any special height above the ground, but is the height of the collimation line above the datum line; referring to Fig. 29 supposing *A* to be a datum mark 100 feet above sea-level and a back sight reading upon this staff is 5.20 feet, it will be evident that the height of the line of sight or collimation must be 100+5.20=105.20 feet. A fore sight reading on staff at *b* gives, say, 1.80 feet. If we subtract the *b* staff reading from the height of line of sight or collimation we obtain the height of *b* in relation to *a,* thus 105.20—1.80=103.40. Now, if we change the position of the instrument to between *b* and *c* and a back sight reading on *b* shows, say, 5.50 then the height of the line of sight for this position will be the height of the ground at *b* plus the staff reading on *b*. Thus collimation line 103.40+5.50=108.90 feet. The height of the line of collimation is found in all cases by adding the reading of the back sight to the height of the station on which the staff for taking the back sight is placed, and the method of reduction consists in adding all the back sights to the reduced levels of the stations upon which they are taken to find the collimation level and subtracting the intermediate and fore sights from the previous collimation level to obtain the reduced levels of the stations on which the intermediate and fore sights are taken.

Fig. 33 shows the form of field book used, with the last example recorded by the collimation method.

Back Sight.	Intermediate Sight.	Fore Sight.	Height of Instrument.	Reduced Level.	Horizontal Distance Chains.	Remarks.
5 .50	...	...	25 .50	20	0 .00	
...	6 .00	...	...	19 .50	0 .00	
...	3 .50	...	...	22 .00	2 .00	
...	4 .20	...	...	21 .30	3 .00	
4 .05	...	3 .50	26 .05	22 .00	4 .00	
4 .50	...	2 .05	28 .50	24 .00	7 .90	
...	5 .50	...	...	23 .00	9 .00	
...	4 .00	...	...	24 .50	10 .00	
5 .30	...	1 .50	32 .30	27 .00	12 .00	
...	2 .80	...	...	29 .50	13 .80	
2 .70	...	3 .30	31 .70	29 .00	18 .00	
5 .40	...	4 .70	32 .40	27 .00	22 .00	
...	4 .60	...	...	27 .80	25 .00	
5 .60	...	0 .10	37 .90	32 .30	28 .00	
...	4 .90	...	...	33 .00	29 .00	
...	3 .70	...	...	34 .20	31 .00	
5 .00	...	3 .45	39 .45	34 .45	34 .00	
3 .90	...	2 .45	40 .90	37 .00	38 .00	
...	4 .40	...	...	36 .50	40 .00	
5 .75	...	1 .90	44 .75	39 .00	42 .00	
...	4 .23	...	...	40 .52	44 .00	
...	3 .75	...	...	41 .00	46 .00	
...	...	3 .25	...	41 .50	46 .00	
47 .70		26 .20		41 .50		
26 .20				20 .00		
21 .50	rise			21 .50		

FIG. 33.

In comparing the Rise and Fall and Height of Instrument systems it is evident that in the case of intermediate sights there is a considerable saving of labour with the Height of

Instrument system in the reducing, as this method dispenses altogether with rises and falls; on the other hand with the rise and fall system there is a check on the reduction of the intermediate sights, as an error in reducing an intermediate sight will effect the reduction of the next foresight and consequently of all the levels after it, but as against this by the collimation method any intermediate sight may be incorrectly reduced and will not affect any of the other levels. By this system levels may check correctly to a bench mark and yet have some intermediate sights incorrectly reduced, therefore important points and not intermediates should be made change or turning points.

The collimation system is objected to by some surveyors because it deprives them of a check, as with the Rise and Fall method, the difference between the totals of rises and falls should equal the difference between the totals of back sights and foresights and also between the first and last reduced levels ; consequently if there are no rises and falls we are without one of these checks, however it is only a check upon arithmetic and can be well omitted. It is impossible to mistake the column, and one calculation is avoided. With the Collimation system the check is quite perfect, the difference between the totals of back sights and fore sights being merely tested against the difference between the first and last reduced levels; with such a simple and efficient system the Collimation method should become universally used.

Reference to the former chapter will show that the entire horizontal measurement was completed before the commencement of the levelling. Although the system is contrary to the practice of many efficient surveyors, when the chain or steel band is used it is the simplest one, and the one least likely to introduce error. The management of the level, as all men of experience with it know, requires great care and attention; in fact, more care and attention than can be well bestowed upon it if the operator has his mind in any way diverted.

Of course, when time is the essence of business, or where despatch takes precedence of minute accuracy, a separate surveyor and chainman may be employed to take the horizontal measurements, which can be called out to the leveller for entry; but, when the urgency is not so great, the latter system will entail a vast waste of the valuable time of the surveyor, who will complete his measurements in less time than will be occupied by the leveller, unless the latter employs an additional staff-holder. Again, if the work is to be thus performed by two surveyors, neither can be held wholly responsible.

The up-to-date method is to read the horizontal measurements optically by means of the stadia reading telescope, as described in Chapter XI., at the same time as the vertical measurements, thus saving a great deal of time and labour.

It would be most inconvenient, on very large works in a new country, to complete the horizontal measurement before commencing the levelling. In a new country it is often necessary to take a section of great length in the direction of a magnetic point, and to take cross sections when there is sufficient reason to anticipate deviation; then it is invariably the custom to move onwards with the complete equipment of the party.

And now a word or two on the importance of accuracy in horizontal measurement.* Generally speaking, the horizontal measurements of a section are very carelessly determined; in fact, in the case of a section of a long incline, the total length recorded as "horizontal" is as often as otherwise the length of the hypothenuse of a right-angled triangle, instead of the length of its base. When this is the case the section cannot possibly accord with the plan, and much confusion arises in the rectification of the former to make it fit the latter. Further, this system of exaggerated measurement produces a considerable excess in the cubical contents of earthwork; and as an example of this we will refer to Fig. 34, which is illustrative of a slope having its base 20 chains in length, and inclination 21 chains.

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* *Vide* "The Practical Surveyor," by the author.

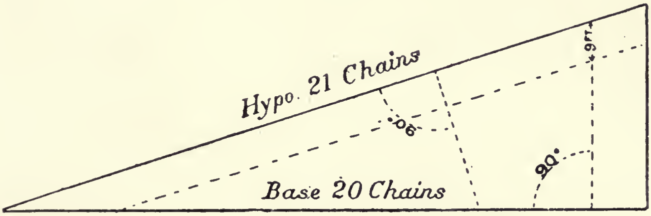

Fig. 34.

Now if a cutting of the plumb depth of 9 feet, and of the width of 12 feet, were made up the slope, the actual cubical quantity of soil removed would be 20 chains × 9 feet × 12 feet=5280 cubic yards; whereas if the hypothenuse measurement were worked from, the quantity would be 21 chains × 9 feet × 12 feet=5544 cubic yards, or 264 cubic yards more than it should be. If, however, for the sake of experiment, we were to invert the figure and for the moment accept the hypothenuse as the base, deducing thereupon such a rectangular height as would accord with the plumb depth of 9 feet as determined on the original base, and to compute the quantity of cubic yards accordingly, we should obtain a quantity in close approximation to the correct one; but a calculation of this kind, I venture to say, would not be made.

Bad or careless staff-holding is also a thing almost certain to produce those small errors which spoil the thorough completeness of a series of levels; and as there is no more difficulty in holding the staff correctly than incorrectly, there is no reason why the correct system should not be followed. I generally enter into a confidential chat with my staff-holder, in which I explain to him the vast importance of his duties—*i.e.*, I endeavour to make him a man of importance in his way—and I never fail to get those duties properly performed. My instructions to him are seven in number, viz.:—

1. Draw out the slides of the staff, and see that the joints are properly locked.
2. When the staff is once held on a point, never move it without being told or signalled to do so.
3. Examine the staff regularly to see that no dirt is sticking to the bottom of it.
4. Always stand erect behind the staff, so that the figures face the level.
5. Do not let any part of the hand come over the face of the staff.
6. When the selection of the spot on which the staff is to be held is left to you, always find a firm piece of ground on which to hold it, and do not in any case put a downward pressure on the staff.

7. If the grass be long, mossy, or spongy, tread it down so that the staff shall always have a firm footing.

In the first item of my instructions I have used the word "slides"; it will, however, often occur that the drawing of one will be sufficient for an entire day's work, in which case no part of the other should be visible.

Some surveyors compel the staff-holder to carry an iron shoe to plant the staff upon, but I never yet saw the advantage to be derived from its employment, although I am informed that it is good on loose, sandy soils. On certain occasions, when levelling across peat bogs and the like, I have instructed the staff-holder to stand steadily on a board and to hold the staff on a piece of roofing slate about a foot square, for reasons which will be obvious enough to those acquainted with such-like places.

Very accurate staff-holding on firm ground can be secured by the attachment to the staff of a small circular pocket level (Fig. 35), which can be obtained at a trifling cost. This level is illustrative of much that a very dull man might not be made to understand from words, or that you could not explain in a foreign country from want of a knowledge of the language..

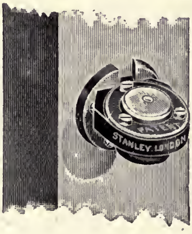

FIG. 35.

CHAPTER VIII.

ILLUSTRATION OF A WORKING SECTION OF A MAIN DRAIN, AND SUNDRY MATTERS CONNECTED THEREWITH.

CONSIDERING our work as a treatise upon levelling and its general application to practice, and keeping in view a consistent order of progression, let us give an example of the preparation of a working section of a main drain, and show, by the figures in connection with it, how utterly impossible it is for a person ignorant of the art of levelling either to lay such a drain as it should be, or to determine the several sizes of pipes that must of necessity be used in its construction, in order to embrace the two great features of thorough efficiency and true economy.

Fig. 36 represents a pasture field of 44 acres, having a somewhat porous subsoil, which I drained, in the year 1880, by laying a drain of the average depth of 4 feet in every furrow.

Having fixed upon a good point of outfall, and determined the direction of the main drain therefrom, I took the horizontal measurements on the line of section, shown at Fig. 37, and drove in a stake at its commencement, and at every interval of 2 chains along its entire length. These stakes, it must be remarked, were truly cut at the tops and driven to the surface of the ground, adjoining turves being removed to facilitate their future identification. Next I took the levels in manner hereinbefore described, setting up the instrument about mid-way between stakes numbered

1 and 2, and alongside stakes numbered 3, 5, 7, 9, 11, 13, 15, and 17, and registered the several staff-readings shown in the field-book (Fig. 37); then working out and reducing the levels on an assumed datum of 10 feet below the B.M. on the top of the stone retaining wall of the ditch, and determining the rise to be 11.19 feet, I took the check levels, shown immediately after the field book, to prove the accuracy of my observations, setting up the instrument for this purpose on stakes numbered 4, 10, and 15.

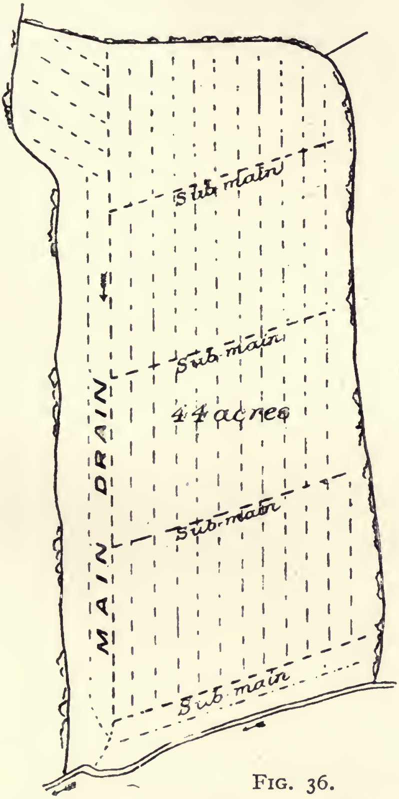

FIG. 36.

I now proceeded to make the section illustrated by Fig. 37. On this section the reduced levels were placed on the left-hand side of the vertical lines, as reference to the figure will show. The bottom of the ditch being at a datum level of 7.00 feet, and considering it advisable to keep the outfall at least 6 inches above it, 7.50 feet was determined as the datum level of the bottom of the trench for the drain, and registered as such on the right-hand side of the vertical line at the commencement of the section, or, in other words, immediately underneath the figures representing the reduced level of the surface of the land.

The next business was to fix the line of the bottom of the trench, and this was done by determining that it should be 5 feet below the surface at stake No. 11, and 4½ feet at stakes numbered 15 and 17. This determined, the line on the section was drawn and the gradients calculated in accordance with the following example:—

	Feet
Datum level at 20 chains =	9.60
Less datum level at outfall =	7.50
	2.10

20 chains = 1320 feet, which, divided by the above difference of 2.10, gives 628, so that the first gradient is 1 in 628, as shown on Fig. 37.

It is most important that the ratios of the inclinations of all the gradients should be correctly determined, because, as a general rule, they form the bases of future calculations.

In the present instance we have to determine the size of the outlet pipe that will be required for the discharge of $\frac{4}{10}$ of an inch of rainfall from 44 acres of land in 24 hours,

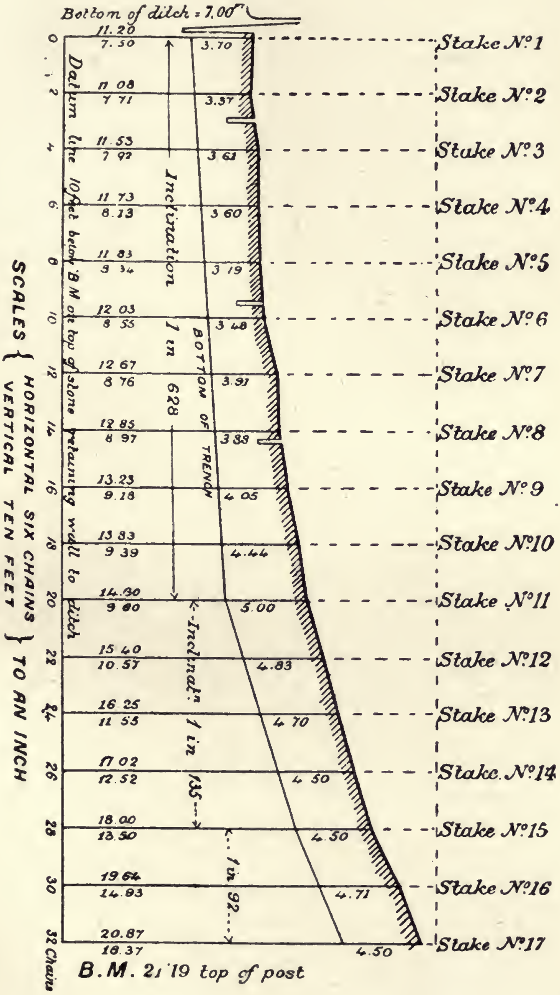
Bottom of ditch = 7.00
11.20
7.50
3.70
Stake No. 1
11.08
7.71
3.37
Stake No. 2
11.53
7.92
3.61
Stake No. 3
11.73
8.13
3.60
Stake No. 4
11.83
8.34
3.19
Stake No. 5
12.03
8.55
3.48
Stake No. 6
12.67
8.76
3.91
Stake No. 7
12.85
8.97
3.83
Stake No. 8
13.23
9.18
4.05
Stake No. 9
13.83
9.39
4.44
Stake No. 10
14.30
9.60
5.00
Stake No. 11
15.40
10.57
4.83
Stake No. 12
16.25
11.55
4.70
Stake No. 13
17.02
12.52
4.50
Stake No. 14
18.00
13.50
4.50
Stake No. 15
19.64
14.83
4.71
Stake No. 16
20.87
16.37
4.50
Stake No. 17
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32 Chains
Datum line 10 feet below B.M. at top of stone retaining wall to ditch
Inclination 1 in 628
BOTTOM OF TRENCH
Inclinat^n 1 in 135
1 in 92
SCALES { HORIZONTAL SIX CHAINS / VERTICAL TEN FEET } TO AN INCH
B.M. 21.19 top of post

FIG. 37.

FIELD BOOK TO FIG. 37.

Rise.	Back Sight.	Fore Sight.	Fall.	Reduced Levels.	Horizontal Distance. Chains.	Remarks.
...	...	...	...	10.00	...	B.M., Top of stone retaining wall to ditch.
...	5.27	8.27	3.00	7.00	...	Bottom of ditch.
4.20	8.27	4.07	...	11.20	0.00	Stake No. 1.
...	4.07	4.19	0.12	11.08	2.00	,, ,, 2.
...	4.87	6.35	1.48	9.60	2.90	Bottom of grip.
1.93	6.35	4.42	...	11.53	4.00	Stake No. 3.
0.20	4.42	4.22	...	11.73	6.00	,, ,, 4.
...	4.32	4.52	0.20	11.53	8.00	,, ,, 5.
...	4.52	6.00	1.48	11.05	9.55	Bottom of grip.
1.98	6.00	4.02	...	12.03	10.00	Stake No. 6.
0.64	5.07	4.43	...	12.67	12.00	,, ,, 7.
0.18	4.43	4.25	...	12.85	14.00	,, ,, 8.
...	4.75	6.18	1.43	11.42	14.40	Bottom of grip.
1.81	6.18	4.37	...	13.23	16.00	Stake No. 9.
0.60	4.37	3.77	...	13.83	18.00	,, ,, 10.
0.77	5.13	4.36	...	14.60	20.00	,, ,, 11.
0.80	4.36	3.56	...	15.40	22.00	,, ,, 12.
0.85	5.17	4.32	...	16.25	24.00	,, ,, 13.
0.77	4.32	3.55	...	17.02	26.00	,, ,, 14.
0.98	5.45	4.47	...	18.00	28.00	,, ,, 15.
1.64	4.47	2.83	...	19.64	30.00	,, ,, 16.
1.23	5.30	4.07	...	20.87	32.00	,, ,, 17.
0.32	4.07	3.75	...	21.19	...	B.M., Top of oak post near.
18.90	111.16	99.97	7.71			
7.71	99.97			11.19		
11.19	11.19			10.00		
			Check	Levels.		
2.67	5.67	3.00				From B.M. to B.M.
3.58	5.66	2.08				
4.99	5.03	0.04				
11.24	16.36	5.12				
	5.12					
	11.24					
Less	.05	for difference not appreciable				
	11.19					

the available fall being 1 in 628, or practically 1¼ inches in a chain. Now, reference to formulae* will show that at the above rate of inclination the velocity of the current in feet per minute will be about 119, at which velocity the outfall pipe should be 12 inches diameter; but were the fall increased to 5 inches in a chain, the corresponding velocity of current would be about 207 feet, at which velocity a 9-inch pipe would be equal to the required discharge.

A glimpse at Fig. 36 will show that the main drain may be diminished in capacity directly it is carried beyond the junction with the first sub-main, and afterwards be further diminished. It is not, however, my intention to enter further into the question of drainage than is necessary to show the importance of our subject.

The next thing performed was the calculation of the depth to which the trench was to be excavated below the tops of the several stakes. This was done—with regard to the first gradient, a similar process being applied to the other gradients—by dividing the fall of 2.10 feet by the number of equal divisions into which the length of the gradient was divided, adding the quantity obtained to the various datum levels in succession, and deducting the new datum levels from the original reduced levels in the manner following:

Diff. of Level = 2.10 feet ÷ 10 = 0.21 feet.

Datum level at stake No. 1 = 7.50 + 0.21 = 7.71 at stake No. 2.
,, ,, ,, 2 = 7.71 + 0.21 = 7.92 ,, ,, 3.
,, ,, ,, 3 = 7.92 + 0.21 = 8.13 ,, ,, 4.
,, ,, ,, 4 = 8.13 + 0.21 = 8.34 ,, ,, 5.
,, ,, ,, 5 = 8.34 + 0.21 = 8.55 ,, ,, 6.
,, ,, ,, 6 = 8.55 + 0.21 = 8.76 ,, ,, 7.

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* *Vide* formulae in Beardmore's "Manual of Hydrology," Ewart's and other works.

Datum level at stake No. 7 8.76+0.21=8.97 at stake No. 8.
" " " 8=8.97+0.21=9.18 " " 9.
" " " 9=9.18+0.21=9.39 " " 10.
" " " 10=9.39+0.21=9.60 " " 11.

For the convenience of deduction, the latter figures were placed (see the section) on the right-hand side of the vertical lines, immediately under the reduced levels, the difference between them and the latter being placed between the line of gradient and the surface line. This operation was proved by the coincidence of the figures of the last addition (viz., 9.60) with those originally determined upon; and also, but not in so reliable a manner, by the scale of the section. I have known surveyors determine the depth of cuttings and embankments by the scale alone, but it is a practice much to be condemned, and one that cannot be productive of first-class work.

It may now be considered that we have completed a working section; but how are we to work from it to obtain the gradients to which we have referred? Thus:—Set up a line of boning rods close to the stakes, so that when erected the line of sight along their tops shall be at a convenient height above, and parallel to, the bottom of the trench. The method of setting up the rods—assuming 6 feet as the convenient height—is to set each rod exactly so much above the stake alongside it as the depth to which the trench is to be cut is short of 6 feet; thus, at stake No. 1 the top of the rod should be 2.30 feet above the top of the stake, and 2.63 feet above it at stake No. 2. The rods should *all be erected from measurement,* the parallel line of sight being a matter of natural sequence if every former operation has been correctly performed.

The parallel line being thus established, provide the man working in the bottom of the trench with a rod exactly 6 feet in length, and instruct him, as the work proceeds, to hold it in an upright position at continuous short intervals on the bottom of the trench to enable the foreman to test the work by seeing that the top of the rod is in exact alignment with the tops of the boning rods.

It is almost impossible to produce a true gradient in an excavation without the aid of either boning rods or sight rails; and yet we continually find important drainage works entrusted to men who have no knowledge even of the existence of such things, and find those men *superintended* (?) by a man whose knowledge is even inferior to their own.

As a rule, the foreman sets up his own boning rods, and levels them transversely; but to enable him to do so, he must be furnished with either a tracing of the section, or a tabulated form of the heights and distances.

The following form I have found to answer very well.—

No. of Stake.	Depth below Stake.	Distance from outfall. Chains.
1	3.70	0.00
2	3.37	2
3	3.61	4
4	3.60	6
5	3.19	8
6	3.48	10
7	3.91	12
8	3.88	14
9	4.05	16
10	4.44	18

No. of Stake.	Depth below Stake.	Distance from outfall. Chains.
11	5.00	20
12	4.83	22
13	4.70	24
14	4.50	26
15	4.50	28
16	4.71	30
17	4.50	32

You may very much assist the foreman by pushing a piece of folded writing paper, with the number of the stake written upon it in soft pencil, into the ground close to the stake.

CHAPTER IX.

SECTION ACROSS A RIVER—CROSSINGS OF WALLS AND FENCES—SPECIAL FEATURES OF A FLAT COUNTRY—OCULAR ILLUSIONS—SUBSIDENCE OF THE SOIL—LIGHT AND SHADE—EXPEDITIOUS LEVELLING—CURVATURE RECONSIDERED—GENERAL REMARKS ON LEVELS OF ASCENTS AND DESCENTS.

HITHERTO we have encountered neither difficulties nor specialities. These, however, present themselves in actual practice, and occasionally form matters of the greatest importance.

Let us imagine ourselves to be interrupted by a river running across the line of our operations, the profile of the bed of which, as well as the level of the surface of the water, must be correctly shown on the section. In an ordinary case of this kind it might be well to calculate the distance across the river,* and drive a stake at each side of it exactly to the level of the surface of the water, and then to take the level to the top of the first stake in the line. For all practical purposes the two stakes would be on the same level; operations, therefore, could be continued from the second stake, and both stakes be left as a basis for subsequent soundings.

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* For mode of calculation, see "The Practical Surveyor," by the author.

As to the method to be employed in taking the soundings, much must depend upon the breadth of the river and the velocity of its current. No method, however, is perfect, and nothing will be more likely to meet the emergency of the moment than a little individual ingenuity.

Having to take the soundings of that somewhat sluggish river, the Wiltshire Avon, to enable me to complete a section which crossed it for about 40 yards in length, and having no boat at hand, I invented the method next described and illustrated by Fig. 38.

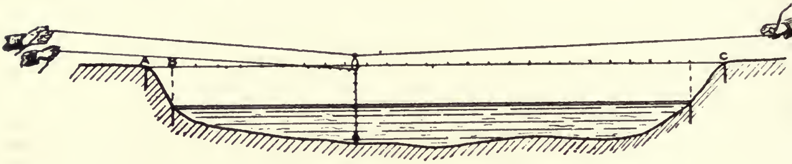

FIG. 38.

Knowing the distance across the river, I provided myself with a ball of fine twine, a stout cord about 45 yards in length, an angler's clearing ring, and a lead plummet. The stout cord being well secured to a stake driven into the bank at *A*, and the point *B* being determined on it as plumb above the stake at the water level, I converted it into a measuring line by tying small strips of red cloth to it at intervals of feet, commencing from the point *B*; then slipping the clearing ring over it, and allowing it to run back to *A*, I attached a length of fine twine to the other end of it; to the other end of the length of fine twine I attached a stone, which I threw across the river to my assistant, who, having picked it up, pulled the stout cord across the river and firmly secured it to the point *C*. My assistant then returned the stone with the fine twine attached to it. I now passed the end of a length of fine twine through the lower opening of the clearing ring, attached the plummet, and divided the twine from the point of the plummet into divisions of a foot each by means of further strips of red cloth; then I tied the fine twine just returned to me to the upper opening of the clearing ring, and threw the stone again across the river to my assistant; the last act towards the completion of this contrivance being the attachment of a second length of fine twine to the upper ring for my own use.

The method of using this contrivance hardly needs explanation: the ring is pulled over all the divisions of the cord *A C*, and the plummet allowed to touch the bed of the river; the depths being read from the vertical line; the lengths from the horizontal one.

I have known a rapid river of the width of three chains so shallow that one could wade through it and take the levels in an ordinary manner, selecting, of course, judicious places for the erection of the instrument. If, however, a river be rapid, and too deep to be waded, a boat is indispensable.

I know of no river in England that I could not strain a divided line or wire across, from which the horizontal measurements could be taken, although in some cases it might be necessary to anchor a number of boats, and join the line or wire to upright boat hooks held in position. If the horizontal lengths could not be measured, they should be calculated from angular observations, taken either with a theodolite or box sextant, or by the stadia observations hereinafter referred to. The entire length across the river should always be calculated, or otherwise correctly determined, the divided line or wire being only accurate enough for intermediate measurements. In cases where boats are at hand, a short sounding line is perhaps the simplest thing to use. A proper sounding line is made of waterlaid hemp, and has its divisions into feet interwoven. It does not contract upon being wetted.

If the surface of the water be rough, as it would be under certain influences of wind and tide, it would not be sufficiently well defined to be accepted as a basis for calculation; it would then be necessary to take an observation across the river to the land on the other side. This observation should not be taken without special regard to the adjustment of the line of collimation. It might be necessary, on account of the length of the observation, to make allowances in respect of curvature and refraction.

We have yet another contingency to grapple with: a piece of water might be so wide in one part as to be beyond the distinct vision in our telescope. In such a case, if the other side could not be levelled to by any available circuitous route, recourse might be had to the following method, which is illustrated by Fig. 39, and which balances the errors of curvature and refraction.

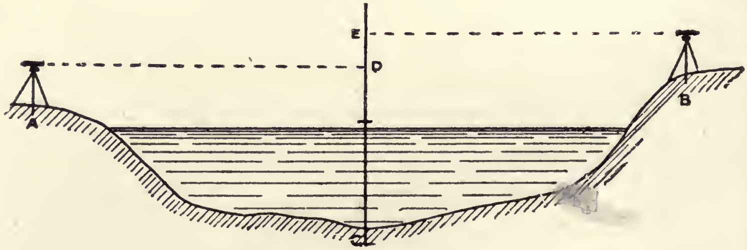

Fig. 39.

Let the boat be anchored about the middle of the river, and let the boatman firmly fix a pole into the bed of the river at *C*; then direct your assistant to partly drive a level course of strong nails round the pole just above the water line, to form a rest for the staff, and to ensure its correct reversal. Set up the level with the line of collimation exactly 4 feet 6 inches above the stake *A*, and read the staff at *D*; then, having crossed the river, set up the instrument at the like height above the stake *B*, and read the staff at *E*, when the difference between the readings *D E* will be equal to the difference of level between the tops of the stakes *A* and *B*.

Bruff, who is a good authority upon levelling, illustrates a method of transferring levels from one side of a river to the other by reciprocal observations. He writes (Fig. 40 being a copy of his diagram):—

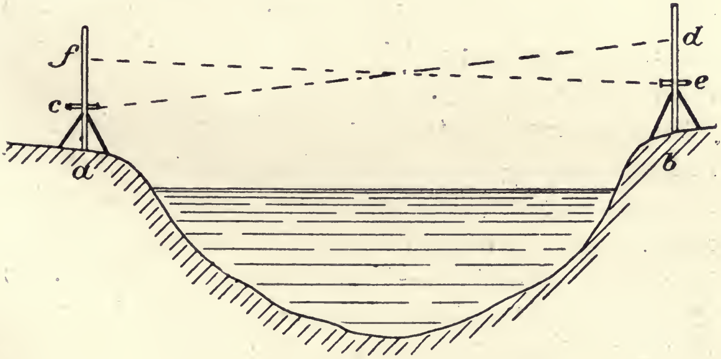

FIG. 40.

"We may illustrate this position by the above diagram —where *a b* is part of the earth's circumference, and *c e* the positions of the spirit level, which are supposed to be level or equidistant from the earth's centre. Now the spirit level being set up at both stations exactly at the same height—

we will suppose 5 feet—and that the effect of curvature on the line of sight *c d* made the reading of a staff at *b* 5.05. The spirit level at *a* being set up at 5 feet will therefore give a *rise* of ·05 from *b* to *a*, notwithstanding we have assumed the two stations to be level. Again, the line of sight *e f* being equally affected will show a *fall* of .05 from *b* to *a*, which is contrary to the previous observation; and as both cannot be correct, or, in other words, higher and lower at the same time, although we have assumed the observations and relative postitons to be correct, we must set one error against the other, by which means the accurate or mean level will be arrived at."

In the cases of creeks or estuaries, the sections of which are often necessary in railway work, or when rivers impede the line in rapid succession, as they often do in new countries, recourse must be had to a boat (either portable or otherwise) and a sounding line; and in very rapid water a sounding chain may be necessary.

Trigonometry presents many methods for determining the horizontal measurements of a section of an estuary or vast sheet of water; but the following may perhaps be the readiest method it affords when a considerable number of distances have to be determined:—At a convenient point (Fig. 41) *C* on the line of section set out the line *C A* of any convenient length, at right angles to *C B*; erect a theodolite at *A*, and take the angle *B A C*, of which the angle *C B A* will be the complement. The calculations will then be, As the sine of the angle 22° 30′: the side *C A* : : sine of the angle 67° 30′ : side *B C*—the formula being, As the sine of any angle : side opposite : : sine of any other angle : its opposite side.

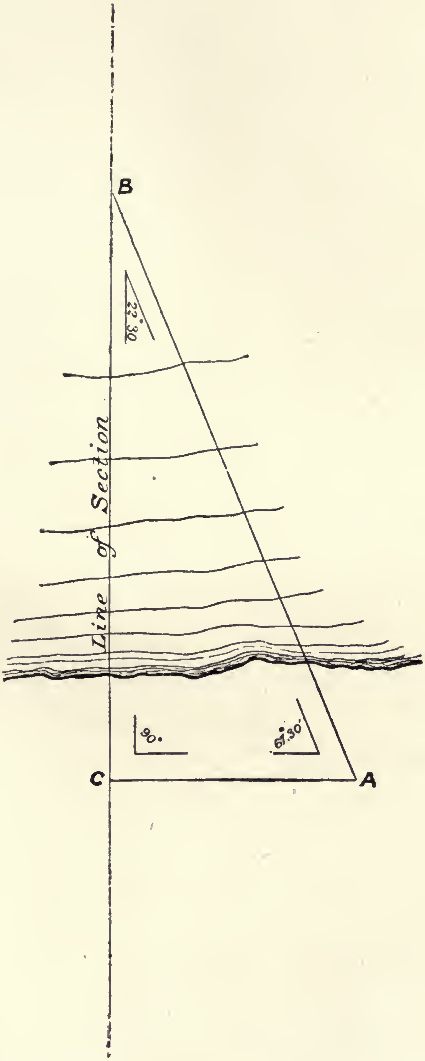

FIG. 41.

Another method of determining the horizontal measurements in question, which may occasionally be convenient, is to assume the side *C A* to be the base of a slope, the line *A B* being the batter, and *C B* the perpendicular; thus, if the angle *A C B*=45°, the batter would be in the proportion of one of the base to one of the perpendicular; if 63° 28′, half of the base to one of the perpendicular; if 78° 58′, a quarter of the base to one of the perpendicular; and so on. If the theodolite were fitted with a spring clip to hold a card with a suitable table of vertical angles, and their corresponding slopes printed on it, these horizontal distances could be determined by the easiest calculation.

These methods necessitate the use of a theodolite. If the level telescope be fitted for Stadia measurements (see Chap. XI.) the direct measurement can be read without the theodolite or any trigonometrical calculation whatever.

The work of levelling is often impeded by the interception of high walls; when, however, the line of section has only to cross two or three of them, it may be well to act, in respect of each of them, as follows:—The wall in question shall be 9 feet high. Take a fore sight at the foot of the wall as you approach it; then measure the height of the wall (which is 9 feet, and consequently must have a rise of 9 feet recorded in respect of it), and enter the next back sight as 10.00, and the fore sight on the top of the wall as 1.00; next enter the top of the wall as a back sight of *nil*, and the ground on the other side as a fore sight of whatever may be the height of the wall, which in this instance shall be 10 feet; then proceed as before, commencing with a new back sight on the site of the last fore sight. The following field book will assist to make this matter clear, and show the land to be a foot lower on one side of the wall than on the other.

Rise.	Back Sight.	Fore Sight.	Fall.	Reduced Levels.	Remarks.
...	...	...	...	20.00	Datum level at first foot of wall.
9.00	10.00	1.00	...	29.00	Top of wall.
...	0.00	10.00	10.00	19.00	Datum level foot of wall at other side.

It may occasionally happen that a wall, especially a retaining wall, shall be of the height of 30 or 40 feet, and that our section may have to cross it. If an obstruction of this kind be met with, the better plan will be to level from one side of the wall to the other by some circuitous route; although the difference in level may, by careful manipulation, be taken with a tape, the ring of which should be attached to the lower end of a correctly levelled straight-edge.*

When a considerable number of high walls have to be crossed in succession, the short metal triangle for fixing the instrument on the top of a wall will be found to be of immense advantage if the level be of other than " Stanley " make. All " Stanley " levels are made with the lower plate terminating in three feet which permits them to be used on walls, masonry, etc., without their stands. In taking levels over a long succession of walls, it will be found advantageous, at some convenient point, to take as long sights as possible from the top of one wall to the top of another, as a check against inaccuracy.

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* Retaining walls batter on the outer face; therefore the end of the straight-edge into which the hook is screwed to receive the ring of the tape should be plumb over the base of the wall.

At the crossings of hedge and ditch fences, in order to insure exact work, staff-readings should be taken on the land at the edge of the ditch, at the bottom of the ditch, and on the land close to the hedge on the opposite side; as it happens, much more frequently than otherwise, that the land on the bank side of the fence is much higher than that on the ditch side, and the difference in level is not perceptible on account of the thickness of the hedge. The height of the bank of the hedge is a matter hardly worth consideration, although the entry of a note on its probable height in the column for remarks in the field book can do no harm.

Much with regard to the general level of a flat country may be observed at the time of the subsidence of a vast inundation. It is obvious enough that the water will gradually recede from the gently rising land, but I venture to say the first appearance of *terra firma* will be made alongside and following the course of the river, and that for some time after its appearance large areas of water will remain in the hollows between it and the higher lands. These floods show us, that which at ordinary times might not be detected, how little the eye is to be trusted in the more delicate parts of levelling, and how important it is, in taking a section through land apparently flat, not to take sights at long distances apart. A marked change of gradient may easily be detected by bringing the eye to the ground and looking along its surface; but it is quite possible, and particularly when grass or other crop is high, that a depression of a foot for a number of chains in length may escape the keenest observation. A man of great experience would detect the presence of many of these depressions in meadow land by the character of the turf; but these pages are not for him.

The eye unaided is not for one moment to be trusted to determine whether land rises or falls—in fact, *apparent* matters respecting gentle slopes are generally most illusory; for instance, if a westward view in the morning shows an apparent gentle rising, that apparent gentle rising may gradually disappear and be converted into an apparent fall as the observer veers to the other points of the compass. These optical illusions are produced by the effects of light and shade, changes of background, varying states of the atmosphere, the laws of perspective, and an almost endless variety of local circumstances and effects; and so generally do they prevail that it is never safe to rely upon purely ocular observations.

Peat mosses and morasses are invariably troublesome to the levelling engineer, and are nearly always a source of trouble to the engineer of works.* In taking levels across them, great care must be exercised in selecting judicious places for the erection of the instrument; and the observer will do well to stand in such positions at its side as will enable him to take both backward and forward observations without moving his feet, or putting greatly varying pressure on either one of them. The staff should be held in manner already described at the end of Chap. VII.

On such extensive marshy lands as are frequently met with abroad, it is often necessary to drive in very long stakes to receive the feet of the tripod and staff, and to take very long observations with much more powerful and larger levels than are employed on ordinary work.

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* *Vide* Life of Mr. Geo. Stephenson, C.E., for construction of railway over Chat Moss.

When the time for taking these very long observations is optional, it will be better to take them during the last two hours of the day before sunset in dry weather, and early in the morning in wet weather, if not misty; otherwise the most distinct reading (in the absence of mirage) can be taken when the sun is shining on the back of the observer and on the face of the staff.

Some years ago I prepared sections for the arterial drainage of a large area in Gloucestershire, and afterwards superintended the execution of the works. In testing the levels week by week, I found all the work in strict accordance with the working sections, till I came to a peat moss, and there I found the bottom of the cutting not so much below the tops of the stakes alongside it, by from 6 to 8 inches, as it was shown to be on the working section. The contractor nevertheless declared the work to be "done right"—I give his expression—and at last it occurred to me that the land might have subsided. Fortunately there was a well-established B.M. within about 15 chains of the point in dispute, from which I levelled, and discovered a general subsidence of a vast area of the moss on either side of the cutting. Our cutting had evidently eventually lowered the entire area of the moss by relieving it of water.

The general remaining difficulties in a country like our own are few and trifling: woodland sometimes impedes rapid progress, but never does more; and ravines, which fortunately are far apart, provide a little tedious work occasionally.

When a plantation, wood, avenue, or any feature productive of an intensity of shade, is approached, it is nearly always necessary to limit the forward observation to the outer boundary of it, as it is difficult, and at times impracticable, without the aid of an artificial light, to read the staff within it; whereas there will be no difficulty in reading a staff held on the outside of its limits when the instrument itself is erected within; neither will there be any difficulty in reading the staff within the limits when the instrument and staff are alike situated in the general shade. On some works the track through woodland is cleared.

An expeditious leveller sets up his instrument quickly, quickly removes it, and nearly always sets it up on the most advantageous site. It is not, however, advisable for the beginner, when levelling upon very steep or undulating ground, to endeavour to erect the instrument to such a degree of nicety as to be able, by a double observation, to read within an inch or two of both extremities of the staff, because such an endeavour would probably result in failure, and entail a re-setting up of the instrument, and consequently a loss of time. He would do well to erect it so as to be quite sure of being able to read his first back sight, thus entering as it were into a kind of compromise between certainty and rapidity, and leaving time and experience to guide him hereafter. Figs. 42, 43, and 44 are illustrative of the erection of the instrument in the most economical positions.

At the conclusion of the first chapter, I explained that the errors due to the curvature of the earth were balanced by the method of using the level on the tripod; yet it may be well to make exception to the rule, which does not *strictly* apply when levels are taken along very lengthy lines of ascent and descent. Reference to Fig. 45 will show

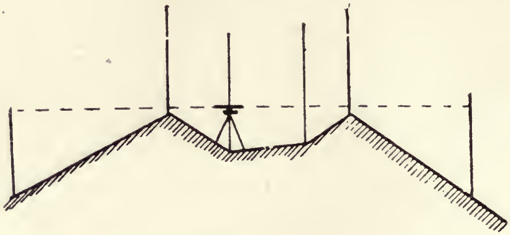


FIG. 42.

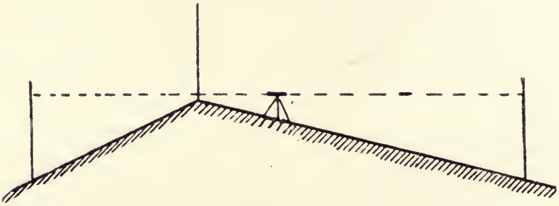


FIG. 43.

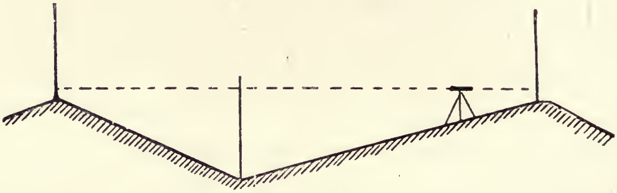


FIG. 44.

that in levelling along either of the lines indicated, there must be a continuously preponderating length of one sight over the other, and that therefore errors due to curvature and refraction must be admitted. The differences, however, between the several lengths of back and fore sights cannot be added together and treated as a whole; on the contrary, each difference must form a matter for separate calculation. It is obvious that the error produced by disregarding the form of the earth can hardly be worth recognition unless the inclination be very extensive.

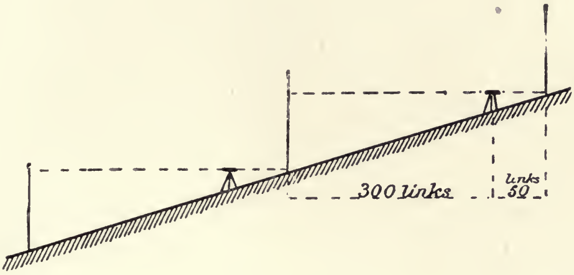


FIG. 45.

It may be well to show that if a hundred similar observations to those shown by Fig. 45 were taken consecutively, the calculation in respect of curvature would be as follows:—

Excess of length of back sight=2.5 chains, which squared=6.25, which divided by 800 (see Chap. I.) gives .0078125 inches; and the latter multiplied by 100, for the number of observations, produces .78125, or a little over three-quarters of an inch. If, however, the excess of the length of one sight over the other were increased to 5 chains on the same total length, the error would be sensibly increased; thus, $5^2=25\div800=.031259\times5$ observations=1.843 inches.

In actual practice the errors introduced by a preponderance of the lengths of one series of sights over those of another are considered as too slight to be regarded. If we wished to be more nice than wise in such cases, we might, when taking levels along continuous lengths of ascent and descent, employ a staff of only 10 feet in length, because, as Fig. 46 will illustrate, such a length of staff must necessitate a near approximation to equi-distant observations.

It is a common practice to use a staff 18 feet long, when levelling in a mountainous country. Some surveyors, when levelling up or down an incline, erect the instrument at some

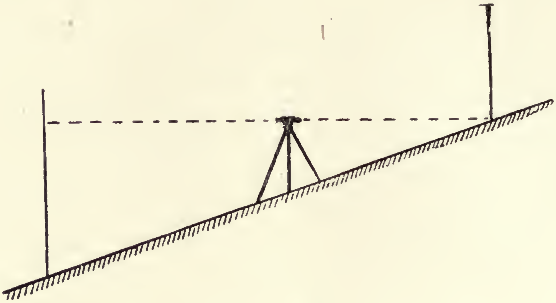


FIG. 46.

distance to the side of the line of operations, with the view of equalizing the lengths of the sights; this system is to be condemned, because it is more likely to increase error than diminish it, and because it wastes time. If, however, the side position be taken to keep the rays of the sun from the object glass, it is unquestionably, for that reason alone, the better one.

CHAPTER X.

TRIAL SECTIONS—CROSS SECTIONS—CONTOUR LINES—COMPROMISE BETWEEN THE LATTER AND TRIAL LEVELS—LEVELS TAKEN FOR ARCHITECTURAL PURPOSES.

A SURVEYOR is often called upon to give an opinion as to the practicability of a scheme, and to report upon its probable cost and otherwise. To enable him to give a well-founded opinion, and to impart the required information, it may be necessary for him to make a section, showing simply the general features of the profile of the surface; and such a section would be termed, according to the magnitude of the proposed work, an *explore* or *trial* section. In the production of this, despatch generally takes precedence over minute accuracy, although it is essential that the principal features of the profile should be correctly determined. In exceptional cases, however, primary importance attaches more to the many features of detail, such even as the bottoms of ditches and brooks, than to the well-marked points of configuration, when it will be necessary to take all the levels with the same care that would be bestowed on the levels taken for a working section. An explore or trial section should always be carefully preserved, as it may, at probably a not far distant future, be of service in checking the accuracy of a working section. Fig. 47 is an example of a trial section which was prepared with the view of ascertaining the fall from a spring on one part of an estate to a defined spot on another part, and reporting upon the best means and probable cost of conveying the water from the spring to the spot defined.

The following (Fig. 47) is a copy of the field book from which the section was prepared:—

FIELD BOOK TO FIG. 47.

Rise.	Back Sight.	Fore Sight.	Fall.	Reduced Levels.	Distance in Links.	Remarks.
...	...	...	...	20 .00	...	Datum 20 feet below top of stone.
3 .10	5 .35	2 .25	...	23 .10	...	
3 .40	5 .70	2 .30	...	26 .50	1,000	
2 .83	6 .43	3 .60	...	29 .33	1,550	
...	3 .40	6 .70	3 .30	26 .03	...	
...	3 .29	6 .82	3 .53	22 .50	2,430	
2 .50	4 .75	2 .25	...	25 .00	2,900	
7 .00	9 .06	2 .06	...	32 .00	3,500	Point of Spring.
18 .83	37 .98	25 .98	6 .83			
6 .83	25 .98					
12 .00	12 .00					

The latter field book differs from the one contained in Chap. VIII., inasmuch as the differences of levels between the points of horizontality are not in all cases determined by the difference of sights taken direct from one point to another. It will be observed that the differences of level between the commencement of the section and 1000 links, and between 1550 and 2430 links of horizontal measurement, are determined by the aid of intermediate observations. These intermediate observations are taken to shorten the lengths of the sights, and may be as many in number as may be convenient.

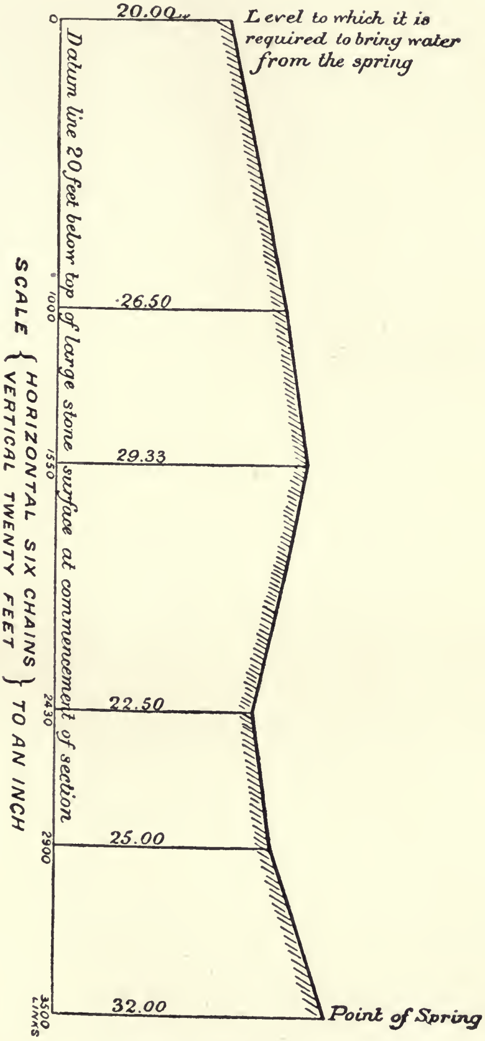

Level to which it is required to bring water from the spring
20.00
26.50
29.33
22.50
25.00
32.00
Point of Spring
0
1000
1550
2430
2900
3500 LINKS
Datum line 20 feet below top of large stone surface at commencement of section
SCALE { HORIZONTAL SIX CHAINS / VERTICAL TWENTY FEET } TO AN INCH

FIG. 47.

In trial sections for important works, the features requiring representation may be as far apart as 20 or 30 chains; therefore it may be necessary, in determining the difference of level from one to another, to introduce a considerable number of intermediate observations.

It will doubtless be perceived that equal importance attaches to every observation taken for the production of a trial section of the kind illustrated, and that my remarks on the minor importance of intermediate sights, contained in Chapter VII., do not in any way apply themselves to these intermediate observations. The intermediate sights of Chapter VII. are simply sights of secondary importance taken between sights of primary importance. The intermediate observations given in this Chapter are equally important with the terminal ones.

We will now enter upon the preparation of a section of a cutting and embankment, introducing in conjunction therewith the method of taking cross or transverse sections, and we will further endeavour to explain the usefulness of the latter.

A section across which shorter sections are taken is, for the purpose of contradistinction, termed a longitudinal section; whilst the shorter sections taken across it are known as cross or transverse sections. Fig. 48 is illustrative of a longitudinal section, showing a cutting and embankment, together with cross sections at the points *A* and *B*.

The level line on the longitudinal section (Fig. 48) shows the base of the excavation and the top of the embankment, and is generally drawn in red, the cutting and embankment being respectively tinted with red and yellow. The following field book (Fig. 48) is precisely of the same character as the

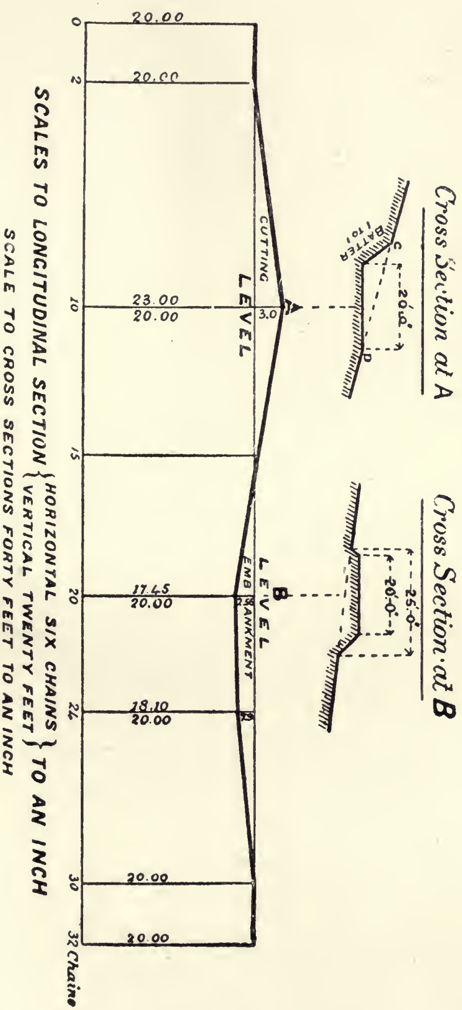
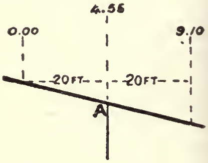
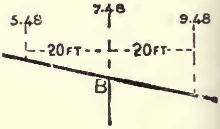

Cross Section at A
BATTER 1 to 1
C
D
20'0"
Cross Section at B
25'0"
20'0"
0
2
10
15
20
24
30
32 Chains
20.00
20.00
23.00
20.00
17.45
20.00
18.10
20.00
20.00
20.00
CUTTING
LEVEL
3.0
A
B
LEVEL
EMBANKMENT
2.55
1.9
SCALES TO LONGITUDINAL SECTION {HORIZONTAL SIX CHAINS / VERTICAL TWENTY FEET} TO AN INCH
SCALE TO CROSS SECTIONS FORTY FEET TO AN INCH

FIG. 48.

one referring to Fig. 47, excepting that it goes so much further as to show the system of taking and registering the observations for the cross sections.

FIELD BOOK TO FIG. 48.

Rise.	Back Sight.	Fore Sight.	Fall.	R.Levels.	Distance. Chains.	Remarks.
0 .00	4 .90	4 .90	...	20 .00	2 .00	Cross
1 .40	5 .50	4 .10	...	21 .40	...	Section *A*.
1 .60	6 .15	4 .55	...	23 .00	10 .00	
...	3 .00	6 .01	3 .01	19 .99	...	
...	4 .94	7 .48	2 .54	17 .45	20 .00	
0 .65	5 .70	5 .05	...	18 .10	24 .00	
1 .90	6 .80	4 .90	...	20 .00	30 .00	Cross Section *B*.
...	4 .90	4 .90	...	20 .00	32 .00	Level on *X* Section.
5 .55	41 .89	41 .89	5 .55			
5 .55	41 .89					
—	—	Level.				

At the points *A* and *B*, owing to the sloping character of the land across our line, it was necessary to take cross sections; but as our work only occupied a short distance from either side of the longitudinal or central section, it was considered that cross sections of the width of 20 feet on each side of it would be sufficient. We therefore, on arriving at the points *A* and *B*, paused and took staff-readings at 20 feet on each side, and entered them in the manner shown in the field book under the heading "Remarks." This system of taking and registering cross sections, which may need explanation, is simple in the extreme:—Sketch a sectional line of the ground, and draw a vertical line through its centre, which represents the position of the line of the central or longitudinal section; then reproduce the letter *A* or *B*, for purpose of reference, under the sectional line of the ground and upon the vertical line; next enter the fore sight taken on *A* or *B* on the vertical line above the sectional line of the ground; and finally, take and register, in the manner indicated, sights on the recorded side distances.

It rarely happens that the surveyor is called upon to make cross sections of any considerable length, although in the cases of sections taken in connection with the formation of lakes, reservoirs, etc., or with the system of contouring, on which I shall hereafter have something to say, the cross sections may be of considerable length, and be equally important with the longitudinal ones. When, however, the cross sections are approximate to the other sections in point of length, it is customary to draw referential lines of section on the plan, and to term them, regardless of their being transverse or otherwise, sections on the lines *A B*, *C D*, etc.

When the preparation of transverse sections necessitates the taking of many observations, their preparation could not well be undertaken conjointly with the work of the longitudinal section; it would therefore be the better plan to drive stakes on the latter at their points of crossing, and take them upon the same datum in an entirely separate part of the field book. To keep the cross sections on the same datum it is only necessary to transfer the reduced levels of the longitudinal section at the points of crossing to the separate part of the field book, and to work from them as you would from an assumed independent datum.

Without sections taken across transversely sloping or irregular ground, correct ideas of the general character of the works could not be formed, neither could the quantities either of material or labour, and consequently their cost, be calculated. Let us determine, by way of example, the number of cubic yards of cutting and embanking shown by Fig. 48. The rule for this determination is: determine all the areas of the cross sections, and multiply the average area of two cross sections by the length between them.

Cross section A=length of $C\ D$×half its perpendicular, viz., 25.5×2.5 ... ... = 63.75 Feet.

Cross section B=for all practical purposes 23 feet×2.55 ... ... = 58.65 ,,

Cross section at 24 chains=20 feet for width of top+1.9 feet for base of one slope, at a batter of one to one, as being equal to both slopes=21.9×1.9 ... ... = 41.61 ,,

Sectional area of A=63.75÷2=31.87×858 feet as equal to 13 chains ... ... = 27,344 ,,

Sectional area of B=58.65÷2=29.33×330 feet as equal to 5 chains ... ... = 9,679 ,,

Sectional area of B+sectional area of C= 100.26÷2=50.13×264 feet as equal to 4 chains ... ... =13,234 ,,

Sectional area at 24 chains=41.61÷2=20.80 ×396 as equal to 6 chains... ... ... = 8,236 ,,

58,493 ,,

58,493÷27=2166 cubic yards of cutting and embankment.

Cross sections cannot possibly be disregarded in works embodying deep cuttings and high embankments, inasmuch as it is necessary to fix upon a quantity to be excavated that will be equal, or nearly so, to the quantity to be embanked; and further, without them the top and bottom widths of the excavations and embankments could not be set out.* I must not, however, stray from our subject.

Nothing can possibly contribute more to the assistance of an engineer, in the development of a new country, than contour lines; but as it is tedious and costly to define them, in respect of such differences of altitude as would render them of thorough practical utility, they are seldom employed. To understand what a contour line really is, let us repair to a large tract of meadow land at the time of the subsidence of a flood, and follow the line of the greatest extremities of the water's reach, which will be distinctly defined by a deposit consisting of a mixture of minute pieces of decayed wood and vegetation. In following this line we shall be following a true contour line—a line which shall be in every part equidistant from the earth's centre.

Now if the latter naturally defined line of contour were well within the limits of the area proposed to be contoured, the surveyor could not do better than adopt it as a basis or datum for all his subsequent contouring observations, because it would certainly be advantageous to define the mark of a high flood and a contour line which would be at no great height above the lowest part of the district by one operation. If, however, the country to be contoured be one of vast expanse, the contour lines should be registers of the comparative heights above the mean sea level, or above some important and well-defined high-water mark. The lines of contour should, as illustrated by the diagram

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* *Vide* works on Railway Engineering as to angles of repose of different kinds of soils for slopes and batters; and also the experiments of M. Schubler on soils.

Diagram illustrative of contour lines, and their application to sectional purposes.

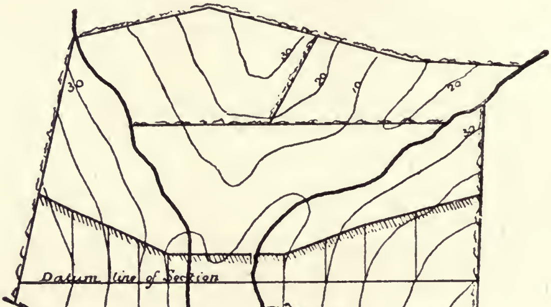

Fig. 50.

(Fig. 50), be drawn much finer than any other lines on the plan; and the greater their number in every 20 feet of altitude, the more valuable the plan. Beyond their use for sectional purposes—and, if correct, a trial section can be prepared from them across the plan in any direction, as shown on the diagram—contour lines are valuable in determining the divisions between varying qualities of soils, particularly in a country where basins are here and there filled with alluvial or other deposit; in determining matters in connection with rates or contributory payments in respect of extensive drainage or flood areas; and also in determining the areas of watersheds.

Contour lines, as generally to be found delineated on plans, are so utterly devoid of accuracy that they are worse than useless. The best time for putting them on a plan is immediately after the completion of a survey, when all the stations of the latter can easily be discovered. The plan to be pursued, having only regard to strict accuracy, should be to take sections through the length and breadth of the country, and on such sections stake out the differences of the altitudes required; and then to trace with the instrument the exact contour of level from stake to stake, and afterwards survey and map it as if it were a fence. This plan cannot fail to produce a correct result, because proof will be afforded of the vertical measurements every time the line of contour is traced from the stake of one section to the stake of another; and because the lines of the survey of the contouring will be connected with the original lines of the survey. In thus tracing the lines, the staff-holder—who should be provided with a quantity of short plaster laths, so that he may stick one into the ground every time the staff is pronounced to be in correct position—should be careful to see that there be no rise or depression between one staff-holding and another; and the observer, in the interest of despatch, need not be particular to an inch in the intermediate observation; but, as has been already explained, his back and fore, or terminal sights, must be correctly observed or the line will not close upon the stake.

A very convenient form of what we may term a compromise between contouring and taking an almost endless variety of trial levels may be effected by levelling all round the enclosures of an estate, reducing the levels to the same datum, and marking them on any existing plan; and when these levels are augmented by the levels of the bottoms of ditches and brooks, and the important elevations and depressions of the central portions of the fields, they will be of nearly, if not quite, as much service to the drainage engineer as the contour lines.

In taking levels of the latter kind, commencement should be made from a conveniently situated point (Fig. 52) *a* near to the outer boundary of the property, and the levelling continued all round such boundary, and back to the point *a*, before any other levels be taken; marks *b*, *c*, *d*, etc., etc., being left on the land at each side of every fence crossed, and a bench mark taken upon the top of the lower hook of every gate passed.

The correctness of the levels being so far proved by the coincidence of the departure and closing datum levels on *a*, the operator will only be required to level from mark to mark, or from B.M. to B.M., alongside the fences, proving the accuracy of his work from time to time by its several closures on the points of level already determined.

I have frequently been called upon to prepare sections across land, in certain indicated directions, for architectural purposes; but I have invariably advised that sections thus prepared would not be nearly as convenient as a series of levels on a common datum, taken upon all the points of elevation or depression in such a manner as to leave a true line of surface gradient between point and point: a *sine qua non* being that the levels thus taken should be correctly defined, by the centres of small circles, on a plan drawn to a scale of not less than 8 feet to an inch, of which Fig. 52 may be regarded as a miniature illustration.

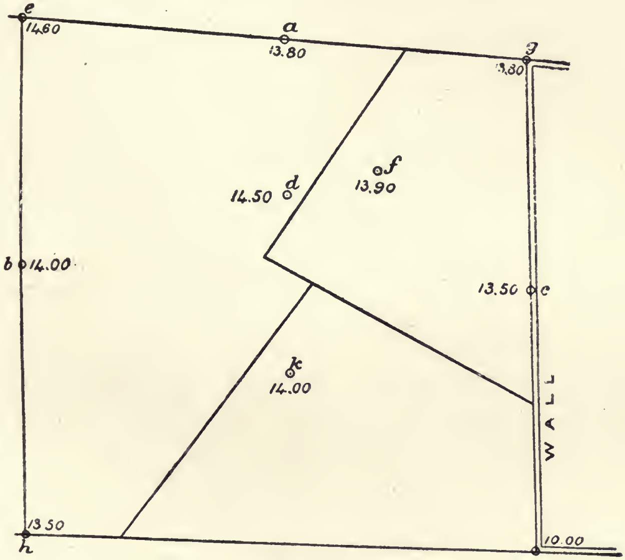

FIG. 52.

To determine the points of elevation or depression in such a manner as to leave a true line of surface gradient between point and point, set up stakes at each corner of the figure, and bring the eye down to the ground to see if there be any points of elevation or depression between the stakes on the outer or boundary lines, and if any be discovered erect stakes upon them as at *a*, *b*, and *c* on the figure. Now decide upon some marked point of elevation or depression within the figure, as for instance, the point *d*, between which and the points *a*, *b*, and *e* there shall be true lines of surface gradient, and erect a stake at *d*; then determine another point, which, for example, shall be the point *f*, between which and the points *a*, *d*, *c*, and *g*, there shall be true lines of surface gradient; and so proceed throughout the figure.

The points of the figure being determined and correctly fixed on the plan by measurement, drive the stakes close to the ground, and take the levels on their tops in the ordinary way.

From a plan of this kind any number of sections can be made, quite irrespective of their positions with regard to points of the compass. For example, if a section were required from the point *h* to the point *g*, the reduced level at its commencement would be 13.50; where it crossed a line drawn from *k* to *b*, it would be 14.00; where it crossed a line drawn from *k* to *d*, it would be the proportionate difference of level between the two points; and so on. By the proportionate difference of level between the points

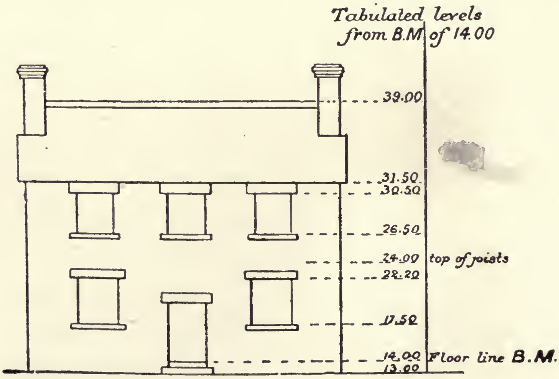

FIG. 53.

k and *d* is to be understood the proportionate difference with regard to the length between the points; thus, if the distance between *k* and *d* were 31 feet, the difference of level 0.50 feet, and the distance from *k* on the direction of *d* to the crossing of the section 15 feet, the proportion would be, as 31 : 15 : : 0.50=0.24, which, added to 14.00, gives 14.24 as the reduced level at the point of crossing.

If a well-defined B.M. be established at some convenient point, as, for instance, on the wall to the right of our figure 53, at a datum level of 14.00 feet, the architect may tabulate all his measurements therefrom, as shown by Fig. 53, and very much simplify matters that are often complicated.

The levels of a site planned for architectural purposes, on which there shall be no greater fall than about 9 or 10 feet, may be taken in the following very simple and expeditious manner:—Erect the instrument on a convenient spot and put each staff reading on the plan alongside a dot, which dot shall define the exact place where the staff was held. Now deduct each staff reading from an assumed datum of say 20.00 feet, and the result will be a table of levels on a common datum.

CHAPTER XI.

LEVELLING AIDED BY THE APPLICATION OF THE SUBTENSE OR STADIA READING TELESCOPE.—THE GRADIOMETER.

ANY one practically acquainted with levelling operations will at once admit that much of the time bestowed upon them is occupied by the horizontal measurements; it is therefore clear that the introduction of the Stadia telescope, which will determine at one observation the horizontal measurement as well as the vertical one, must be in the interests of despatch and economy.

The Stadia is a device for ascertaining the distance of the staff from the telescope by measuring the angle subtended on the staff by auxiliary points, webs, or lines on glass fitted in the diaphragm of the telescope. The geometric principle upon which it is based is that the lengths of parallel lines subtending any angle are in proportion to their distance from its apex. If two fine cross webs or lines on glass or preferably Stanley's points are fitted to the diaphragm where the image is formed, the space which they subtend upon a staff or other object, with known graduations upon it, bears a direct ratio to the distance of the object from the points or webs in the telescope; therefore knowing the distance subtended on the staff, its distance from the telescope can at once be determined.

In accordance with the law to which I have referred, it will be quite clear that if at a distance of 50 feet the length of staff observed between the horizontal cross webs or points be equal to 0.86 feet, the portion that would in like manner be observed at a distance of 100 feet would be 1.72 feet; and at a distance of 200 feet, 3.44 feet. We have therefore the means of determining any distance between the instrument and the staff by the rule of simple proportion; for instance, if it were desirable to determine the distance from the instrument to the staff when the length of staff-image contained between the points was 4.55 feet, the calculation would be—

As 1.72 : 4.55 : : 100=264½ feet.

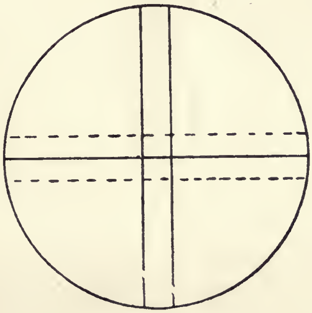

FIG. 54.

If the additional lines (Fig. 54) are so adjusted as to enclose exactly one foot of the staff-image in respect of 100 feet of distance, every division of Sopwith's staff which represents a hundredth part of a foot will represent one foot of distance; thus, if the length of staff-image contained between the two lines were 2.75 feet, the distance from the instrument to the staff would be 275 feet.

In all modern instruments the Stadias are fixed to read 1=100.

The iridium points[*] of the diaphragm contained in Stanley's Improved Level, and illustrated by Fig. 55, are altogether better calculated for determining horizontal distances by Stadia reading than spider lines, and particularly so when very long observations are taken, as the covering webs with their iridescence make exact reading at long distances rather difficult.

At a distance in front of the object glass equal to its solar focus the image and the object are equal in size, consequently as no angle is subtended at this distance the focal length of the object glass must always be added as a constant. Also, as the distance required is from the centre of the instrument, and not from the object glass, the distance from the object glass to the centre of the instrument must also be added, thus if the solar focus of the object glass be 12 inches, and the object glass is 6 inches in front of the centre of the instrument the total distance to be added is 18 inches, or 1.5 feet; this is called the constant of the instrument, and must be added to every measurement taken. This constant is usually marked in the lid of the case containing the level.

To obviate the necessity of the simple addition of this constant to each horizontal measurement, Porro, an Italian, in 1823, fitted between the object glass and the diaphragm an additional lens which he called an anallatic lens. The focus of the object glass with this arrangement coincides with the vertical axis of the instrument, and the anallatic lens focus overlaps the object glass focus and carries the rays on to the diaphragm. The apex of the measuring angle coinciding with the vertical axis obviates the necessity of adding the constant. This arrangement entails considerable loss of light and power to the telescope, besides the inconvenience of having an internal lens which becomes bedewed and cannot be got at to be cleaned, and as the only saving is the very simple addition of the constant it cannot be recommended. The idea that the ordinary open telescope will not give accurate results at all distances by means of Stadia readings plus the constant is entirely erroneous.

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[*] Now generally known as subtense points.

The precision and accuracy of good Stadia work is not nearly sufficiently appreciated, as with proper care it will produce results better than chain measurements, especially in rough country, and the saving of time and labour is great.

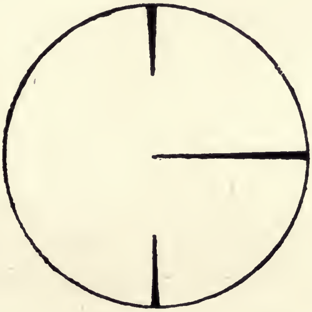

FIG. 55.

An instrument fitted for Stadia measurement is also especially useful for taking the horizontal measurements when preparing a section across a river or estuary, and would be the means of avoiding the more complicated contrivances described in Chap. IX.

Stadia lines or points have not been generally accepted on account of the prevailing idea that difficulty attaches to the registration of the distances as part of a continuous measurement. I think, however, if we were fairly to place on one side of the scale the trouble of chain measurement, and on the other the difficulty of converting Stadia measurements from the instrument to the several staff-holdings into measurements of continuity, the balance would preponderate in favour of the latter. For myself I see no kind of difficulty in registering the distances, as the above example (Fig. 56) will show; but it would be necessary at all times to take a staff-reading at the instrument to adopt my system.

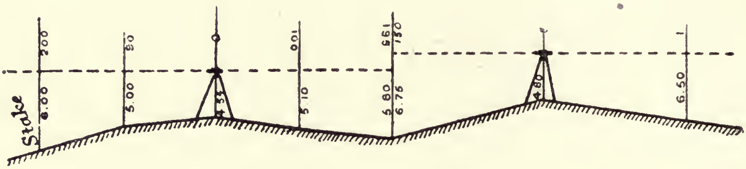

FIG. 56.

As no one will be foolish enough to work out the distances by proportion when he can read them direct from the staff, in manner already explained, I will consider those on the figure to be read direct from the staff. Those figures above the lines of sight show the distances in feet from the instrument; those below show the staff-readings.

The following form of field book is illustrative of my system of registering the readings taken in a continuous line of measurement.

Measurements to the crossings of fences, or other defined points, may be taken by this system with much greater facility than with a chain; and I am certain, from having practically tested it, that it must, within a moderate limit of time, supersede the old one. If any trifling errors of measurement should occur, they might easily be corrected to make the section accord exactly with an accurately prepared plan; but, for general purposes, when due care has been bestowed on the work, the errors of horizontality will be too trifling to be worth consideration.

FIELD BOOK REFERRING TO FIG. 56.

Rise.	Back Sight.	Fore Sight.	Fall.	Reduced Level.	Distance in Feet.
...	...	...	...	50 .00	Datum below stake at commencement.
...	6 .00	5 .00	...	...	200— 90=110.
...	5 .00	4 .54	...	...	110+ 90=200.
...	4 .54	5 .10	...	...	200+100=300.
...	5 .10	5 .80	...	...	200+195=395.
...	6 .75	4 .80	...	...	395+150=545.
...	4 .80	6 .50	...	...	545+161=706.

When very long distances over inaccessible places have to be measured, the angle subtended by the Stadia lines or points, may exceed the length of the staff; in such cases Stanley's Gradiometer (Fig. 57) will do all that is desired, besides being a most valuable instrument for many other purposes.

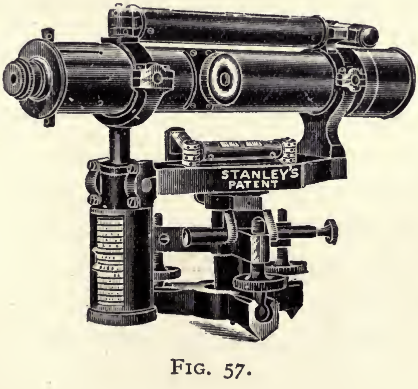

FIG. 57.

This instrument, while performing all the duties of a first-class level, is designed also for taking vertical inclines at small fixed angles for railways, irrigation and drainage works, steep incline levelling, etc., etc., and also telemetrical readings up to great distances.

In general construction, as regards telescope, stand, etc., it resembles a level, and when set at zero is equal in *every* way to one of the best, with the additional advantage that it may be used for rapid work without the trouble of setting up by the levelling screws, as the telescope may be levelled at any sight by means of the Gradienter drum and milled head. The Gradiometric arrangement is effected by the telescope being mounted in trunnions, one pair being adjustable vertically; the amount of elevation or depression is indicated by a drum carrying an open extended scale graduated to read rise or fall from 1 in 12 to 1 in 1,200, which may be conveniently and distinctly read without the use of a vernier.

The additional parts do not increase the bulk of the case and add very little to the weight.

By its use a great saving of work is effected. For instance, for a town drainage in which it is desired to work out an inclination, say the levels indicate a fall of 10 feet between the extreme points: if the line the drainage is intended to take be measured, however angular or zigzag it may be, and the length of that line be divided by the amount of fall, this will give the gradient; say the line of streets measures 5,000 feet, this, divided by 10 feet, gives a gradient of one foot in 500. Therefore, if the drum be set to that proportion all the pipes may be laid directly without further setting. The gradients for any railway may be instantly found by merely turning the drum until the telescope sights, up or down the incline to be measured, a reading on the staff equal to the height of the instrument, and taking the reading of the drum at the position of the indicator.

For levelling steep inclines it also saves a great number of settings up, as, instead of levelling for, say, every 14 feet rise or fall, the gradient of the total distance can be taken and also the distance measured by stadia reading, when the incline is not too great for taking one reading with telescope level, or by gradient reading when this cannot be done, and by adding the staff reading, to the distance divided by the gradient, and deducting the height of the instrument the difference of level can at once be ascertained.

Example: Sighting staff at a gradient which falls conveniently upon it, say 1 in 35 and this reads 8.7 feet. Distance measured as explained later say 735 feet, then $\frac{735}{35} = 21$ ft. $+8$ ft. 7 in.$=$29.7 ft. deduct height of instrument, say 4.9 feet, difference of level 24.8 feet.

For measuring long distances beyond the range of the stadia lines or points in the diaphragm, or for measuring distances on inclines, the Gradiometer will also be found very useful, as by taking the difference of any two suitable gradients the base distance is given without calculation for difference of hypo and base.

If the gradient be not very steep or below the height of the staff, the simplest method is to sight the staff with telescope level and take the staff reading; say this is 12.45 feet, then set the gradient drum to 1 in 100 and again take the staff reading and say this is 4.30 feet the difference between these readings$=$8.15 feet. Strike out the decimal point which multiplies it by 100 and we have the base distance 815 feet.

For shorter distances a larger base upon the staff may be taken, thus giving greater accuracy, for instance, if the gradient drum after taking the level reading be set to 1 in 50 and the resulting difference divided by 2 any error in taking exact readings is reduced by one half or 1 in 33⅓ and divide difference by 3; or in 1 in 25 and divide difference by 4; or 1 in 20 and divide difference by 5, etc. Any error of reading would be reduced by one-third, one-fourth, one-fifth, etc.

The difference of readings obtained by either of the following two gradients will also give base measurement without any calculation whatever: 100 & 50 | 66⅔ & 40 | 60 & 37½ | 50 & 33⅓ | 33⅓ & 25 | 25 & 20 | 20 & 16⅔ | 12½ & 11⅑ | 11⅑ & 10 |

Example: Suppose the top of the staff is below level altogether; turn the drum until the top of the staff is sighted in the telescope; say the gradient of this is 27½; go on turning until the gradient 25 is indicated and take the staff reading; say this is 12.75, then move the drum until gradient 20 is indicated, and take the staff reading: suppose this to be 3.40, then 12.75—3.40=9.35. Omit the decimal point and the measurement reads 935 feet which is the horizontal distance. The two most suitable gradients would of course be used according to the position.

Distances may be set out with equal facility with the Gradiometer by the subtense method, by working out a subtense suitable for the distance. This is easily done by dividing the distance required by any two numbers having a difference of the required subtense, the result being two gradients, that when worked with, will give that subtense at the required distance.

Example: If distance required to be set out is 650 feet. A suitable size for an object to be plainly visible at this distance would be 10 feet. Then take as divisors two numbers having a difference of 10, say 10 and 20.

$$650 \div 10 = 65$$

$$650 \div 20 = 32\tfrac{1}{2}$$

These two gradients will give a subtense of 10 feet at a distance of 650 feet, and all that is necessary is to send a man out in the required direction with a 10 foot rod (preferably having **T** ends, thus ⊢⊣, for long distances, to facilitate distinct reading), and signal him to move farther off, or nearer until the length of the rod, held vertically, is exactly covered by the movement of the telescope caused by revolving the drum between gradient 65 and 32½.

It is always preferable to make the subtense as large as possible, as the larger it is the more accurate the result will be. All distances set out by this method are base distances, no matter what the difference of level may be, and such figures for divisors should be used as give the gradients below 100. Gradients between 12 and 65 are the best and quickest to work with, and with care more accurate results are obtained than with chaining.

Thus, at one operation, a distance may be set out or measured, the difference of level taken, and also the gradient ascertained, and the drum can instantly be set to zero and all ordinary levelling operations continued.

If preferred the Gradient drum can be divided to percentage gradients .001 to 8 instead of ordinary gradients 1 in 12 to 1 in 1,200.

CHAPTER XII.

LEVELLING WITH THE THEODOLITE.

ALTHOUGH for general levelling operations the theodolite is not to be recommended, there are exceptional times when it can be used with much advantage. The *greatest care,* however, must be bestowed on its adjustment* before any levelling operation be attempted with it.

The theodolite is otherwise especially useful for determining altitudes, and altogether supersedes the level for taking sections up very steep inclines, and for making trial sections when the latter are only required to show the principal features of the profile, and when despatch is more important than minute accuracy.

To take the levels up an incline having an altitude of, say, 400 feet by the back and fore sight principle, it would be necessary, in all probability, to set up the instrument from thirty to forty times, and take from sixty to eighty readings of the staff; whereas, by using the theodolite, the altitude could be determined from one observation, and the details of the section taken in much less time than would be occupied by the ordinary process of levelling. Fig. 58 is illustrative of the method of taking a section up an incline with the theodolite and determining the altitude.

To produce a section of the kind illustrated by the figure, erect the theodolite at *A*, and at *B* erect a boning rod exactly to the height of the centre of the telescope, directly over the axis of the instrument, so that the line *C D* shall be parallel to the line *A B*, which represents the main feature of the incline, and send your assistant to points determined upon to erect the boning rods *E* and *F* in the line *C D*. Now take the angle of elevation from *C* to *D*, enter it in the book, remove the instrument, erect a boning rod in its stead at the same height as the boning rod *D*, and commence the chain measurement from *A* to *B*. The heights of the boning rods *E* and *F* must be taken when they are arrived at in the course of chaining; and all the minor elevations or depressions may be taken from the line *C D* by the aid of a boning rod to be carried by the assistant. The latter boning should be of considerable length, and should be contrived to be moved by a line over a small pulley-wheel at the top of the upright. When the depressions are in excess of 5 feet below the line *C D*, the surveyor must go to the nearest boning rod, and, taking sight along the line, direct the assistant by an upward or downward motion of the hand the height to which he must pull the

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* This should be explained by a surveyor.

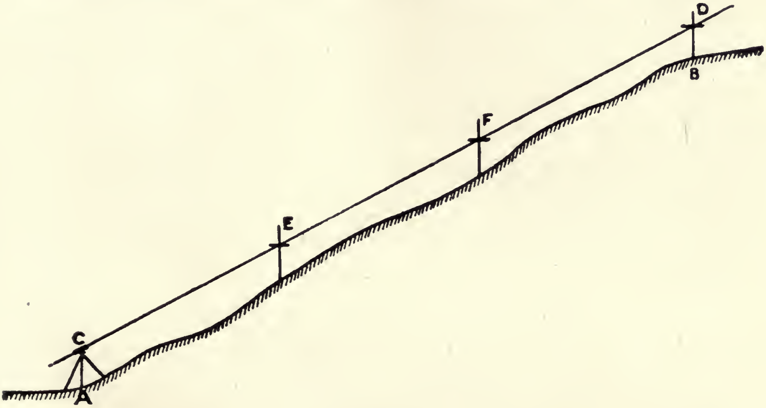

FIG. 58.

slide. This system almost speaks for itself; it is simply determining all the inequalities of the surface by measurements from the line *C D*. Now erect the instrument at *D* to the exact height of the boning rod, take the angle of depression from *D* to *C*, and enter it in the field book.

The angle of elevation being registered as 25° 32′, and the angle of depression as 25° 28′, mean of 25° 30′ may be regarded as the correct angle of elevation. The distance from *A* to *B* being 2500 feet, let us compute the altitude. This is done by multiplying the natural sine* of the angle by the measured distance or hypothenuse, thus:—

Nat. sine of 25° 30′=.4305111 × 2500=1076.27 feet=the altitude required, subject to correction for curvature and refraction.

We now require the length of the base of the incline to enable us to prepare the section, and this is to be obtained by multiplying the measured distance or hypothenuse by the cosine* of the angle, thus:—

Cosine of angle of 25° 30′=.9025853 × 2500=2256.46 feet =the length of the base of the incline. The length of the base, however, may be determined from the difference between the hypothenuse and base in respect of each chain's length as sometimes defined on the reverse side of the vertical circle of the instrument, or by the direct application of Euclid I. 47.

To make a trial section of the kind referred to with the theodolite, a series of vertical angles are taken as shown by Fig. 59.

It is, however, advisable to keep the number of angles to the lowest possible limit; to set up all the boning rods before commencing the work, to enable you to take a double observation at each erection of the instrument; and to take the reverse angle at the termination of the section for proof. The angle to be worked from must in each case be the mean between the angle of elevation and the angle of depression; and when the difference between the two angles is in excess of six minutes, they must be taken again for correction. In trial sections the points of minor elevation and depression, such as those between *A* and *B* (Fig. 58), are omitted.

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* For the sine and cosine see trigonometrical tables.

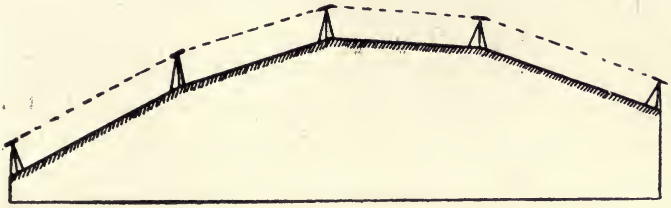

FIG. 59.

The theodolite is also used for setting out gradients, such as those required for carriers in water meadows, sewage carriers, roads where these are required to be at gentle gradients from a contour line of hilly country, underground works, etc., etc. To use this instrument for tracing gradients, clamp the vertical limb to the required angle of elevation or depression, when the telescope will be in the actual line of gradient required, which may be extended by the following very simple process. Provide your assistant with any kind of rod or staff about 5 feet in length, and instruct him to hold it in such a manner that the upper part of his hand shall be at the same height as the telescope, and to hold it with the hand in this fixed position at convenient intervals in the required direction, in such positions as will enable you to read at the top of his hand with the cross webs. The assistant, however, must be careful to so far assist you in selecting his positions as to leave no important elevation or depression between any of the points on which he holds the rod for observation, and must carry with him either light papers or some other contrivance for distinctly defining the several points on the line as he proceeds. By this method of procedure in a very mountainous country, tracks of many miles of roads have been accurately defined prior to staking them out and making working sections.

To enable us, however, to set the vertical limb of the instrument to the required angle, it is necessary that we should know approximately the length of the line to be traced, and the rise or fall from the commencement of our gradient to its termination; thus, if the length were 1840 yards, and the fall 40 yards, we should have a gradient of 1 in 46, which would require an angle of 1° 15′, as will be seen from the table at the end of this chapter.

It will occasionally happen in a mountainous country, or one presenting much irregularity of profile, that the gradient traced out will not terminate sufficiently near to the desired point to be quite satisfactory. When this is the case, the length of the line traced must be measured, and the difference of level between the end of it and the desired point of termination taken, from which we shall be able to determine how much the angle requires to be increased or diminished. As an example, let the measured length be 4500 feet and the difference of level 6 feet. The readiest way of determining the angle will be to divide the height of 6 feet by the measured length for the natural sine, and refer to the trigonometrical tables* for the corresponding angle.

TABLE OF VERTICAL ANGLES AND THEIR CORRESPONDING RATES OF INCLINATION.

Angle.	One in.	Angle.	One in.
° ′		° ′	
0 .15	229	7 .36	7½
0 .30	115	8 .8	7
0 .45	76	8 .45	6½
1 .0	57	9 .27	6
1 .15	46	9 .52	5¾
1 .30	39	10 .18	5½
1 .45	33	10 .47	5¼
2 .0	28	11 .19	5
2 .15	25	11 .53	4¾
2 .30	23	12 .32	4½
2 .45	21	13 .15	4¼
3 .0	19	14 .2	4
3 .15	18	14 .55	3¾
3 .38	17	15 .56	3½
3 .35	16	17 .6	3¼
3 .49	15	18 .26	3
4 .6	14	19 .59	2¾
4 .24	13	21 .48	2½
4 .45	12	23 .58	2¼
5 .0	11½	26 .34	2
5 .12	11	29 .44	1¾
5 .27	10½	33 .42	1½
5 .42	10	38 .40	1¼
6 .0	9½	45 .0	1
6 .21	9	53 .8	¾
6 .43	8½	63 .28	½
7 .7	8	75 .58	¼

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* Trigonometrical tables are printed in pocket form for field use. Some surveyors have abstract tables printed on cards for special uses.

As an instrument for setting out long straight lines of sections the theodolite is of great value, particularly in an undulating country, and when the configuration of the surface of the earth is such as to necessitate tunnelling, it is indispensable. The headings of a tunnel must be driven to the greatest mathematical nicety to ensure a correct closure.

CHAPTER XIII.

Town Levelling—Bench Marks reverted to.

WHEN the surveyor is called upon to take the levels of a town, and to prepare sections of the several streets for sewage or other purposes, he will find it advantageous to commence his operations at the lowest part of it, because, by doing so, he will be enabled at once to decide upon a datum that will be certain of being below all the ground hereafter to be levelled. A little thought is generally necessary to the determination of the method of procedure; but, generally speaking, it is better to level along the greatest length of street, to leave bench marks for branch sections at all the junctions with the streets, opposite underground cellars, and at other convenient points, and to simply confine the attention to one line of operation. This system keeps the head quite clear, and is less likely to introduce error than any other. When the main section is taken, the others can be made in their order of requirement by departing from a bench mark at a junction with the principal street and closing upon another. Following this system throughout the town, there will be no necessity for check levelling, as, all the levels being on the same datum, the last reduced level of any branch section should coincide with the reduced level of the main section at the point of juncture. The levels to the floors of all the underground cellars are better taken at the completion of the street levels.

If the town be levelled for trial purposes, or for the purpose of assisting to estimate the cost of any projected scheme, the establishment of bench marks will be quite sufficient; but if it be levelled for the preparation of working sections, the lines of the sewers or other works should be properly set out. In setting out lines of working sections in towns, stout spike nails are generally employed in lieu of the stakes shown in the example of a working section (Fig. 37), on account of the difficulty of penetrating the hard material of the road. As to whether a section should be taken along the middle or side of a street, circumstances alone can guide us; but in setting out a work of narrow excavation in either position, it would be better to keep the nails or stakes so far to the side of the trench as to be out of the way of the excavated soil. Occasionally it may be more convenient to mark the kerb of the pavement at the necessary intervals with a chisel than to drive either stakes or spikes; and in some very narrow streets, where no pavement exists, it may be found better to work from nails driven into the walls. There is, however, an almost endless variety of contrivances for fixing the points of level in a town.

The remarks on shade contained in Chap. IX. are applicable to many features of a town. When, however, the shade is so intense that the staff cannot be read, or when actual darkness is encountered — as it often is in back or subterraneous passages, cellars, etc.—an artificial light must be thrown upon the face of the staff.

The deal straight-edge, mentioned at the conclusion of Chap. II., used in conjunction with a mechanics' level, is often a useful adjunct to an engineer's equipment for determining levels of floors of cellars or places which may not admit of easy or direct access.

Inasmuch as it is difficult to dissociate levelling from the many branches of engineering that call it into request, it is difficult to write a work on it without referring to them. Land drainage has already been referred to in Chap. VIII. by remarks equally applicable to town sewerage. It may here be right to make a few general remarks on those details of small town and village works, which, from the want of a scientific knowledge, and particularly a knowledge of levelling, are often so grossly mismanaged. The laying of a sewer by the aid of sight rails—and it is difficult to lay one correctly without their aid—is a very delicate piece of work that cannot be performed by an untrained person. Again, a truly and well-laid sewer at a lesser gradient is more likely to be effectual than one at a greater gradient laid badly. Sewers with apparently inefficient falls, by being properly laid and supplied with modern inventions, can be made to act most satisfactorily. It is equally important that steep roads should have their falls adjusted both longitudinally and transversely, in such a manner as to free them from the damaging velocity of currents,* etc.

I have a few further remarks to make on bench marks. The latter should partake of the character of permanency, no matter for what purpose the levels or sections may be required; and particularly should they do so when the district in which they are established is one within the limits of a general practice. By commencing upon the system of establishing permanent bench marks upon a judiciously selected datum, and by adhering from time to time, in the ordinary course of business, to the same system and datum, the work of future operations will be considerably facilitated, and such a general knowledge of the district acquired as must sooner or later be of value.

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* *Vide* the experiments of Du Buat.

The Ordnance Survey Department has established registered bench marks throughout this country upon the datum of the Liverpool mean water mark, and *generally* speaking they may be accepted as correct, particularly in urban districts, where they are invariably marked on permanent structures; nevertheless there are good reasons for advising the pupil to adhere strictly to levels taken by himself, and only to use the Ordnance bench marks for the purpose of checking.

An instance of something that actually occurred may here be mentioned:—

A few years ago I was despatched into Oxfordshire to take the levels for a new watercourse, about seven miles in length, in connection with the works of the Thames Valley Drainage. Operations were commenced on a well-defined Ordnance bench mark on a county bridge, and concluded on another one equally well defined, with the result that the difference of level determined by those observations and the difference obtained by deducting the datum level of one bench mark from that of the other was, in this very flat country affected by neither obstacle nor difficulty, very considerable. The discrepancy so surprised me that I carefully looked to the adjustment of the level, and relevelled the track, only, however, to prove the accuracy of my former observations.

The line was afterwards subjected to two more level tests, one by myself and one by another surveyor, with a result that showed the maximum difference of our four series of levels to be under three inches.

Now, if these particular bench marks had been accepted as correct, and, to meet some matter of special convenience, works had been extended from them in opposite directions, with the view that the work lying between them should be entered upon at a later date, what would have been the result of their being so accepted?

Bench marks intended to be of a *permanent* character should not be made upon temporary structures, or upon those that have been undermined; neither should they be made on structures of doubtful foundation, or on those that have been injudiciously erected on the slopes of a wet and shifting soil. Our commonest literature teems with accounts of the subsidence of the surface into old and imperfectly propped mines. Some years ago we were confronted with the news of the subsidence of an entire town in Austria into old subterraneous workings. My attention was more particularly directed to this part of our subject from having observed the great number of Ordnance bench marks—evidently intended to be permanent—that are cut upon the most temporary structures. Bench marks formed upon the posts of field gates may unquestionably be of service for a moderate length of time—perhaps during the execution of some work to which they have special reference—but I fail to see the value of the indication on a map, intended for the *permanent* service of the nation, of the levels of such bench marks as are cut on the posts of ordinary field gates, or structures that cannot remain much longer.

It is by no means uncommon to find slips of land carrying everything with them; to find the lower walls of buildings on wet slopes separated in bond from the upper walls; and to discover the settlements of foundations on soils of which the upper green sand may be cited as a fair example. Settlements on the latter kinds of soils are often concealed by the well-known system of planting ivy to cover the walls —a system often dishonestly resorted to to enhance the value of property.

CHAPTER XIV.

INTRODUCING A FEW USEFUL INSTRUMENTS—REMARKS ON OFFICE MATTERS — SECTIO-PLANOGRAPHY — GENERAL REMARKS—EXAMINATION PAPERS.

AMONGST the number of useful instruments that are more or less associated with levelling, are the Aneroid Barometer, the Clinometer in its various forms, and the Apomecometer. The Aneroid Barometer (Fig. 60), which is specially manufactured for the use of the surveyor, engineer, topographer, and tourist, is a most valuable instrument for the easy determination of distant altitudes to within a certain degree of accuracy. Taking into consideration the very comfortable manner in which trial sections can be made from levels taken with this instrument, when used in conjunction with a good map; also for such other preliminary levels as are necessary to enable the engineer to report or decide upon matters of water supply (either by

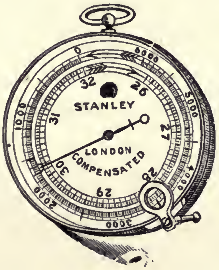

FIG. 60.

lift or gravitation), the depth of mines, etc., it is almost astounding that it is so seldom brought into requisition; in fact, there need be no hesitation in saying that a more general acquaintance with it, in its latest and most improved form, would be the means of imparting to it a very much wider utilization. It is fitted with a movable indicating needle, which is set to coincide with the registering needle at the commencement of any operation, or at the moment of departure from one place to another; and the difference of level between the places of departure and arrival is the difference between the readings of the instrument, as pointed to by the two needles. Mr. Stanley's instrument is fitted with an engraved line index on the same plane as the divisions, and carries a glass of high magnifying power, which much facilitates the reading. By carefully focussing the glass reader, and being minutely careful to read it correctly, really reliable results will be obtained. It is, however, important to good observation that the magnifying glass should be brought directly over the point to be observed, and that in taking the observation the eye be placed directly over the glass. Oblique observations through glasses are erroneous.

In a series of observations, taken with the view to the production of a section, the indicating needle should not be moved from the level to which it was set at the point of commencement, with which level every other should bear a direct comparison; in other words the level taken at the commencement of the series should be regarded as the level of a datum line. To make the levels taken more reliable, a pair of aneroids adjusted exactly to the same sea level should be carried, both of which should be read as a check against inaccurate observations. In fact, it is just as necessary, in the interests of accuracy, to read two aneroids as it is to read two verniers on the horizontal limb of a theodolite; and every surveyor will admit the necessity of the latter. Aneroids have already found favour with several good engineers, one of whom considers that when used in pairs they are quite sufficient for general railway work in hilly districts, and that three-fourths of the time usually occupied by levelling in such districts might be saved.

From my own experience I can testify that the aneroid is further useful for checking the levels taken with a spirit level on a hilly country, but that it must be laid aside when the question of the rise or fall of a few inches, or even a foot, is the all-important one.

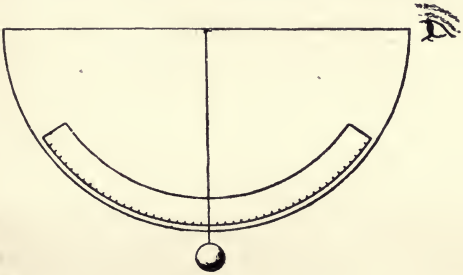

FIG. 61.

For topographical levels, the aneroid is really the only instrument.

The Clinometer is an instrument made in various forms for taking the vertical angles of inclines, and is particularly valuable for testing the accuracy of the batters and slopes of cuttings and embankments, and for determining the difference between the measured length of the hypothenuse and its base. Fig. 61 is illustrative of a rough and ready kind of clinometer, which can easily be made to a sufficient degree of nicety for many purposes from a piece of hard semicircular board, about 4 inches in radius, a fine silk cord, and a bullet about an ounce in weight; and, like other clinometers, can be divided to show the angle of an incline, the gradient of a slope or batter, and the difference between the hypothenuse and base.

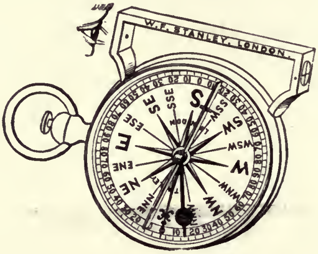

FIG. 62.

Figs. 62 and 63 are illustrative of improved forms of clinometers, Fig. 62 being of watch form, and Fig. 63 in the form of a rule. Fig. 62 is the more convenient instrument for taking the slopes of inclines by the observation of lines parallel to them at the height of the eye of the observer; but Fig. 63 is to my mind the more *generally* useful instrument, inasmuch as it substitutes the sight level illustrated by Fig. 9, and contains, in addition to the divisions

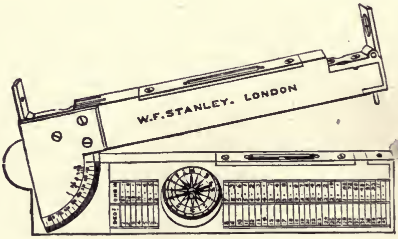

FIG. 63.

of the other, a table of angles and their corresponding gradients, and admits of being fixed for purposes of observation; whereas the accuracy of observations taken with the instrument illustrated by Fig. 62 would be entirely dependent upon the steadiness of the hand, unless perchance there should be a fixed object close by to which you could sidle for support. The latter instrument, however, is much used by geologists for taking the inclinations of strata, and for their purposes is more generally looked *across* than in the position indicated by the eye of the figure. Fig. 64 is an illustration of Abney's Reflecting Clinometer. This popular instrument, which is about 4½ inches in length, and enclosed in a neat case for pocket convenience, is perhaps the best form of clinometer for general purposes. Used independently, and with good observation, it gives the vertical angle of an incline, or the inclination of a slope or batter, to a sufficient degree of accuracy; and used in conjunction with a table, the deduction to be made in respect of each chains length of the hypothenuse of a right-angled triangle to reduce it to the length of the base.

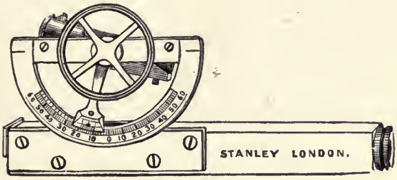

FIG. 64.

The parts of this clinometer are—a spirit level, attached to which at right angles, and moving on the same axis with it, is a limb carrying a vernier, reading into an arc divided in degrees for the registration of angles of elevation and depression to a maximum of 60 degrees. The arc is also divided to show certain corresponding rates of inclination. A sight tube divided horizontally in its interior carries a reflecting mirror in its upper part alongside an aperture, placed immediately below the bubble tube by which the bubble is reflected. The vernier reads to ten minutes.

To test the adjustment of the instrument, bring the indicating point of the vernier to the zero of the divided arc, and look through the sight tube from one certain fixed point or object to another, which shall have been determined to be upon the same level, when, if it be in adjustment, half of the bubble standing in the centre of its run will be reflected immediately above the lower edge of the reflecting mirror, which will centre the point or object on which the observation is directed.

To determine the vertical angle or slope of a natural incline, observe a line parallel to it, and so turn the milled-edged wheel as to throw half of the reflection of the bubble upon the lower edge of the reflecting mirror, which will centre the point on which the observation is directed. The vernier moving on the same axis as the bubble tube will give indication of the angle required.

In the case of a slope or batter of a cutting or embankment, the actual line of surface may be observed, instead of a line parallel to it.

It will be observed that the rates of inclination are read from the *side* of the vernier; as an instance, when the vernier is set to register an angle of 45 deg., its side will show that the corresponding rate of inclination s one to one.

The clinometer may occasionally, with much advantage in point of convenience, be substituted for the theodolite. For determining the exactness of the inclinations of batters and slopes it will be found a much more expeditious instrument than the level, and with good observation nearly as reliable a one.

I once reduced the measurement of the very hilly lines of an Inclosure survey to horizontal measurement by the aid of a temporized clinometer of the character illustrated by Fig. 61, and succeeded in satisfying the Inclosure Commissioners as to the accuracy of the survey, notwithstanding that they had rejected a former survey of the same country, and that my map could hardly be called an approximation to the one rejected. I name this to show that the clinometer is an instrument to be relied upon, and not one of the many that have been produced more to satisfy the ends of theoretical imagination than to meet the demands of practical requirement.

The Apomecometer is a useful instrument for determining the heights of buildings, trees, etc., by reflection, and being in the form of a circular box, 1¼ inches in diameter, and three-eighths of an inch in thickness, can be as conveniently carried in the pocket as a small watch. It was invented by Mr. R. C. Millar, A.R.I.B.A., in accordance with the principles which govern the sextant and optical square; in fact, the only difference between it and the latter, irrespective of size, is that its reflecting mirrors are permanently set for the observation of an angle of 45 degrees instead of 90 degrees. The following are extracts from the inventor's description of it:—" The instrument consists of two mirrors, *A* and *B*, (Fig. 65), fixed in a small box, at such an angle, that, by the production of their planes till they meet, the angle *A D B* would equal 22 deg. 30 min. And because the total deviation of a ray of light, after reflection successively at each mirror, is double their inclination, the angle *E C H* is equal to 45 deg. *H E* represents the vertical height required; *H C* the horizontal line; *A E* the ray of light, or reflection of the image at *E*, striking the mirror at *A*, and from that reflected to the glass at *B*, half of which is silvered and formed into a mirror; so that, on looking through the aperture at *L*, the instrument being held in the hand in the same position as shown, the point *H* is seen by direct vision through the plain half, while the point *E* is seen reflected in the mirror. These two points must be made to agree exactly—in fact, overlapping each other in the glass at *B*. This is done by moving the instrument backwards or forwards along the horizontal line *C H*.

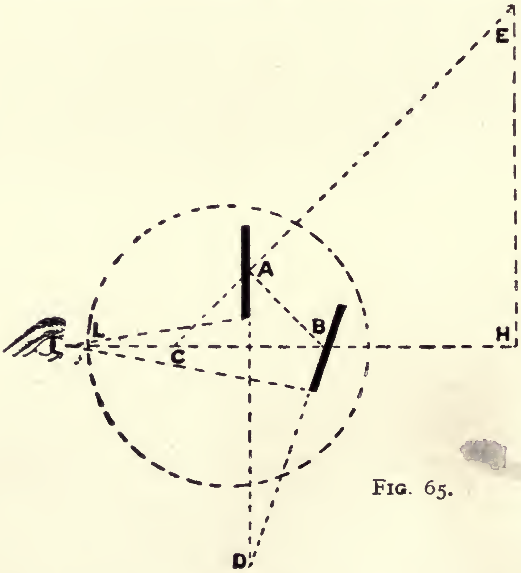

FIG. 65.

The whole accuracy of the working depends on assuming a mark at a proper level with the eye, and in a vertical line with the higher extremity of the height we are about to measure, and also measuring exactly to where a perpendicular if let fall would drop. . . . There are a few isolated cases in which it will not act; as when a building is erected on the summit of a steep hill, in such a manner that we cannot approach it at some side or corner in order to assume a point on a level with the eye. It is also necessary, in taking a height, to be able to recede from the perpendicular line to such a distance as to have a clear space equal to it. However, this condition would not prevent the height of a house in a narrow street being obtained, for we are not bound to stand opposite to the height measured, provided both points chosen are in a vertical line."

Horizontal distances can be determined by using the instrument on its side after the manner of a box sextant. The inventor, after referring to the fig. (Fig. 66), says: "A base line is all that is necessary in order to take the observations. The angles at *A C D* and *F* are taken with the instrument by moving backwards or forwards along the base line *A F*. Half *A D* equals *A B* or *B G*, the distance of the buoy at *G*; half *C F* equals *E F*, or the distance of the other buoy from the base line. The distance *H K* equals

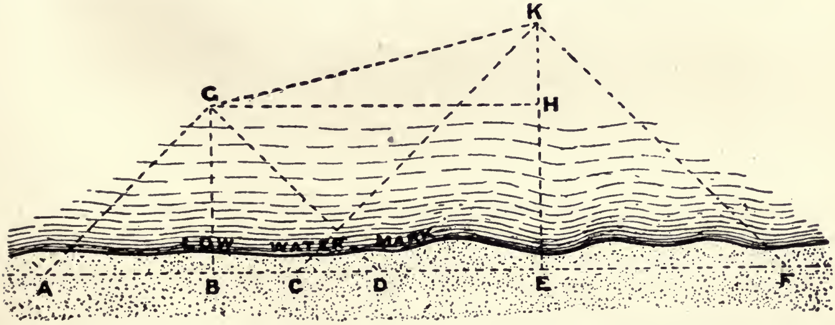

Fig. 66.

E K minus *B G*; therefore in the right-angled triangle *K H G* the sum of the squares of the sides containing the right angle is equal to the square of the hypothenuse, or the distance *G K* between the buoys." The latter, however, is only an application of the apomecometer to one of the many well-known means of calculating inaccessible distances. The maker, Mr. Stanley, has, to my mind, carried his ideas of pocket convenience to too great an extreme in the manufacture of this instrument; in fact, I am certain that if it were increased from 1½ to 2 inches in diameter, it would be a better instrument, and then would not exceed the size of an ordinary gentleman's watch. This increase of size, which would of course necessitate the employment of larger mirrors, would considerably facilitate the taking of observations by admitting a larger field of view, and would be very much less trying to the eyes. Any one practically acquainted with the use of *small* reflecting instruments knows well that it is not always easy to place himself in the exact angular position. An observer with the apomecometer must be careful that the brim of his hat does not intervene between the instrument and the ray of light which carries the reflection of the upper object.

Having formed a general acquaintance with levelling and the nature of sections, it may be well to give brief consideration to the materials and appliances that are generally used in offices in the preparation of sections. My opinion is that every section of a work of magnitude should be drawn upon the best drawing paper, mounted on brown holland, which can now be purchased of almost any given dimensions; and that the best method of procedure would be to fix the paper by means of weights or drawing pins, so that its lower edge, near to which the datum line would be ruled, should be parallel to the edge of the table, and to work from the latter by the aid of a **T** square as if it were a drawing board. As, however, a table with a square edge would be inconvenient for many purposes, a false edge or movable strip of hard wood, as illustrated by Figs 67 and 68, might with much advantage be fitted to it. Fig. 67 shows the strip in section, and Fig. 68 shows a plan of part of it. It will be observed that the tongue of the false strip fits nicely into the groove ploughed into the edge of the table, and that it is held in position by means of the flush pins *A A*. To keep the table from splitting, and likewise to prevent the pin-holes from becoming enlarged, pieces of dovetailed boxwood, *B B*, are inserted at every nine inches of the length of the table, and particularly at both ends of it, to carry the pins.

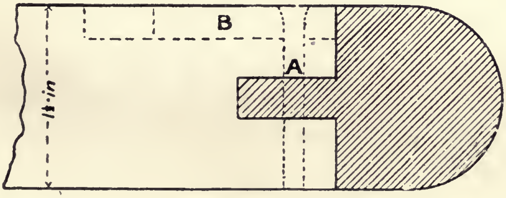

FIG. 67.

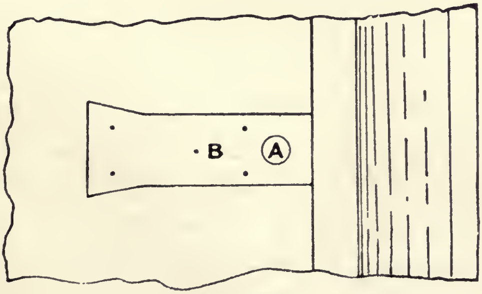

FIG. 68.

In some instances, however, it may be more convenient to fix a steel straight-edge, either by the aid of weights or the clamp shown by Fig. 69, parallel to the datum line, and to draw the vertical lines from a vulcanite set-square. Again, a drawing board of 4 or 5 feet in length, by about 18 inches in breadth, may be especially convenient, as it can be so readily moved that it does not monopolize the table.

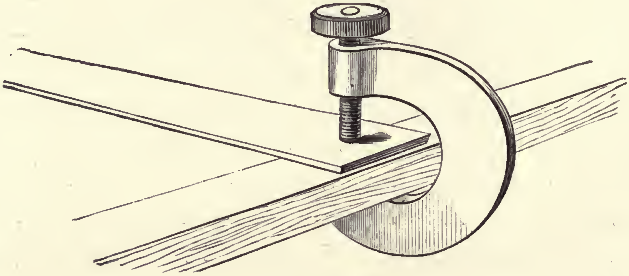

FIG. 69.

With a view of facilitating the work of plotting sections, paper ruled in faint lines to suitable scales for both horizontal and vertical measurements, was many years ago introduced under the name of "section paper"; and very useful it will be found for the purpose.

With the view of removing the difficulty that has often been found in associating the plan and section so as to convey to the minds of other than professional men a clear understanding of the precise character of contemplated works, sectio-planography has been introduced. This, as will be seen on reference to Figs. 70 and 71, is simply a drawing made by transferring the section to the drawing or plan of the surface, on which all embankments should be tinted yellow, and all excavations pink. Sectio-planography is a very convenient form of drawing for appending to reports, and one that has the advantage of completeness in itself. So convenient and complete is it that a non-professional gentleman could with ease study it over his breakfast table, whereas he might be much perplexed with a detached plan and section.

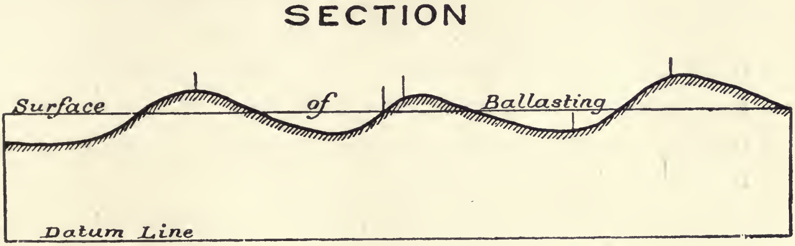

FIG. 70.

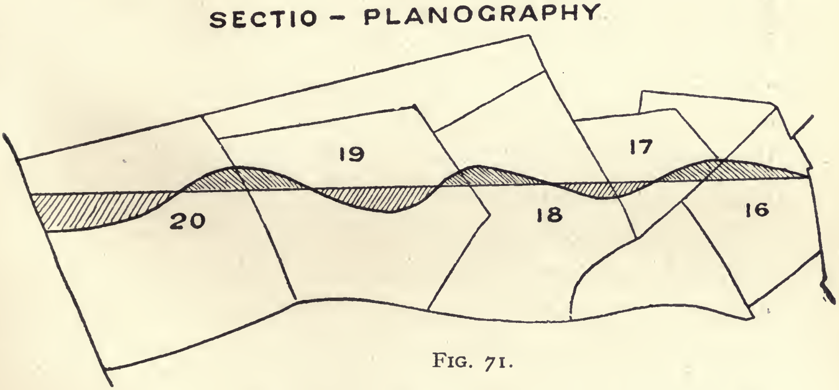

FIG. 71.

In parting with our subject, much as I should like to reiterate those remarks which point out to the student the errors he may without due caution commit, I will only say. Read them again, with an emphasis equal to their weight: Concentrate your endeavours on the one thing, and for all time remember that there is nothing so likely to be fatal to it as an endeavour to grasp another at the same time.

The levelling engineer must often be brought into contact with many phases of human character. At one moment he may be looked upon almost as a benefactor to his kind; at another, condemned, ridiculed, or ordered off. Nor is this all. Sometimes he is looked upon with horror, as being in charge of a small but awfully destructive implement of warfare on three sticks, which he is empowered by the Government to make use of indiscriminately; and anon with that peculiar form of rustic amazement which is inseparable from a vacant gaze and open mouth. Again, he is confronted by the individual whose long-continued course of incredulity has made him quite invulnerable to either the front or side attack of scientific opinion, and who is fairly well portrayed in the character of the old drainage foreman in that very interesting little work, "Talpa: or, the Chronicles of a Clay Farm;" but with this exception, that the old foreman did at last admit that the "devil on three sticks" was a thing to be depended upon, "notwithstandihg forty years' experience to the contrary."

The examination papers appended are arranged to assist the pupil to pass any examination on the subject of levelling; and, considering that they embody questions taken from the examination papers of the Institution of Surveyors, they should be of service to any gentleman desirous of becoming either a member or professional associate of that body.

Hints on omissions from this work will be thankfully received by the revisor, no matter from whom they may come.

EXAMINATION PAPERS.

1. What is meant by the apparent or optical level? Pages 1 to 6.

2. What is the true level? Pages 2 to 6.

3. Give any illustration of a sectional segment of the earth's mean surface, showing the lines of apparent or optical level and true level. Figs. 1 and 2.

4. Give an illustration of proof of the spherical form of the earth. Fig. 4.

5. Does the curvature of the earth cause an apparent elevation or an apparent depression of an object viewed at a distance? Pages 35 and 36, and Figs. 27 and 28.

6. What effect has the curvature of the earth upon the apparent level at a distance of four miles? Illustrate this by a diagram, and show the calculation. Pages 5, 6, 35 and 36, and Figs. 5 and 28.

7. Show the effect of curvature upon the apparent level when the distance is given in yards. Any convenient distance in yards may be assumed. Page 5.

8. Show the like when the distance is given in chains. Page 6.

9. What is meant by a section? Page 42.

10. Give a descriptive illustration of the datum line. Page 42.

11. What is meant by two places being on the same level?

Ans.—Two places are on the same level when they are equidistant from the earth's centre; or, in other words, when they are equidistant from the datum line.

12. What is refraction? and how does it affect a long observation? Page 35 and Fig. 27.

13. Supposing an object coincides with the horizontal web of a levelling telescope (when adjusted for observation) at a distance of 4 miles, what would be the correction required? Pages 36 and 37, and Fig. 28.

N.B.—In the latter question the height of the instrument is disregarded.

14. What is the diaphragm of a level? Explain this by an illustrative sketch of an ordinary one. Pages 32 and 33, and Fig. 25.

15. What is the line of collimation? Describe it, and likewise the adjustment of the level in respect of it. Pages 30 and 31, and Fig. 24.

16. Describe the effects of parallax, and explain the causes of its existence. Pages 28 to 30, and Fig. 23.

17. Remove the diaphragm from the instrument, re-insert it, and put the instrument into pefect adjustment.

18. Give a good reason why it is important that the horizontal measurements should be accurately taken, and that the measurement of every hypothenuse should be reduced to the measurement of the base. Pages 58 and 59.

19. What other means are there of obtaining an approximate section of ground in the absence of the usual level? Pages 14 and 125.

20. When is it advantageous to use the theodolite as a levelling instrument? and describe the advantages of its use. Pages 112 to 118.

21. Draw an imaginary section, show thereon a line representing the bottom of a proposed drain, and calculate the gradient of such line. Pages 62 to 70.

22. Give an instance of a time at which it might be advantageous to use the reflecting levels. Page 14, and Figs. 10 and 11.

23. What arrangement is best as to the relative distance of your level from the back staff and fore staff when you can choose? and why? Pages 39, 81, and 82.

24. Give a descriptive illustration of the use of boning rods. Pages 8 and 68, and Fig. 6.

25. Rule a form of field book, classify the following sights, and work out the reduced levels upon a datum line of 50 feet below the point of commencement.

Back Sight.	Fore Sight
2.20	10.10
1.15	13.45
0.93	11.11
9.98	3.11
13.75	1.19
9.78	2.10
4.14	5.09
7.17	8.17
14.00	5.00
7.50	7.68
5.25	5.20
6.32	7.21
8.40	7.06

26. What is meant by a contour line? Page 95.

27. Make a sketch of a contour plan, showing a section across it made solely from the contour lines. Pages 95 to 97, and Fig. 50.

28. Show the means of taking a cross section of a river. Pages 71 to 78.

N.B.—Two means at least should be shown.

29. Give an illustration of a system of compromise between a series of trial sections and contour lines. Pages 98 to 100.

30. A brook being excavated 3 feet deep, 2 feet wide, on the bottom, and having batters of 1 to 1, required the cubical contents in yards per chain ?

Ans.—In this case the top width of one batter is taken for the two batters. The calculation is therefore thus:—Depth=3 feet × (2 feet + 3 feet) = 15 × 66=990 ÷ 27=37 yards nearly.

31. The brook being 4 feet deep, 3 feet wide on the bottom, and having batters of 1½ to 1, required the cubical contents in yards per chain ?

Ans.—In this case the top width of one batter would be taken for the two batters, and it would be one-fourth more than the depth, thus:—Depth=4 feet × (3 feet + 5 feet) = 32 × 66 = 2,112 ÷ 27 = 78 yards.

32. Describe the method by which you would determine an altitude from the length of an incline, and its vertical angle. Page 114.

33. Describe the method by which you would obtain the horizontal base of a section from the length of the hypothenuse and the vertical angle. Page. 114.

34. Give a short description of a levelling operation aided by stadia observation, and name anything that may occur to you as being favourable to the latter. Pages 102 to 106.

35. Give a description of a bench mark, and explain the use of bench marks generally. Pages 43, and 121 to 123.

36. Assign a good reason for the necessity of calculating gradients, say of the bottom of a watercourse, and the bottom of a pipe drain. Pages 64 to 68.

37. What is the principle of the balance reflecting level? Fig. 11. Pages 12 to 14.

38. Should you at any time expect to find the height of your level stakes affected by a subsidence of the soil? Page 82.

39. Describe the chief advantage possessed by Stanley's new engineer's level over the dumpy level in general use. Pages 23 and 24.

40. For what uses is a clinometer specially valuable? Pages 127 to 131.

41. Give a short description of the apomecometer. Page 131.

42. How would you determine the number of cubic yards of soil to be removed from any work which was irregular in its cross sections? Page 94.

43. When might you employ the aneroid barometer with advantage? Pages 125 and 126.

44. What is the sectio-planography? Give an illustrative sketch of it and describe its advantages. Page 137.

45. Do matters of light and shade affect levelling operations? Pages 82, 83 and 120.

46. For what is the gradiometer useful? Pages 107 to 111.

47. What are the advantages of the platinum-iridium reading points to the diaphragm of a level over the old spider lines or cross webs? Pages 21, 104 and 105.

48. Give a general description of the use of Abney's reflecting clinometer. Pages 129 and 130.

49. How do you determine the size of a level? Page 24.

50. On an extensive moor or morass, what measures could you take to keep the level in a true position, and likewise to secure a correct reversal of the staff? Pages 81 and 82.

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THE END.

STANLEY SURVEYING INSTRUMENTS

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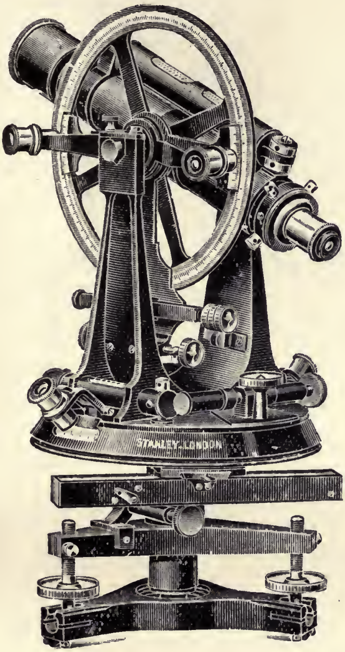


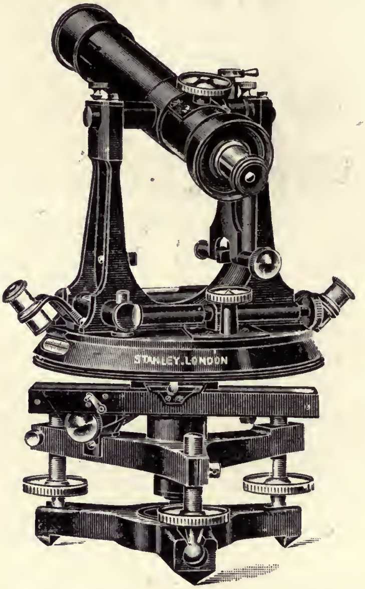
4-in. New Model Transit Theodolite, finest work, as engraving above, to read to minutes	£26	10	0
5-in ditto, ditto, ditto	28	0	0
6-in. ditto, ditto, to read 20 seconds	30	10	0
Sliding Stage for above, extra...	1	10	0
With Quick-Setting Ball Joint, extra...	2	10	0
Either of the above with Illuminated Axis, and Lamp, Striding Level, and Diagonal Eye-piece, extra... ...	4	10	0

If without Trough Compass, £1 less.

The above are with Solid Round Stands ; if Framed Stands, extra	1	0	0

STANLEY SURVEYING INSTRUMENTS

TRADE **STANLEY** MARK



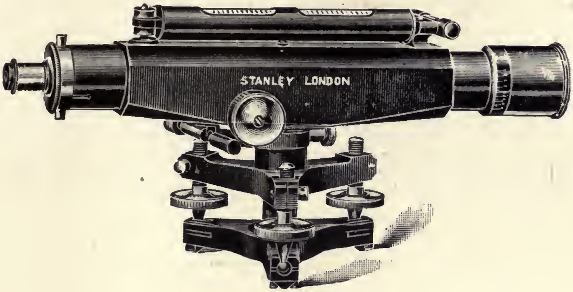
5-in. STANLEY RAILWAY THEODOLITE, a perfect tool for hard work.

With Trough Compass	£24	0	0
Without Compass	23	0	0
6-in. ditto, ditto. With Trough Compass	26	0	0
Without Compass	25	0	0

Box SEXTANT, best make, divided on silver, reading single minutes to 120 deg., with Telescope, Sun Glasses, etc., in Solid Leather Sling Case	£4	4	0

STANLEY SURVEYING INSTRUMENTS

TRADE **STANLEY** MARK



ENGINEER'S LEVEL.

In this Level the centre is cast in one piece with, and directly upon, the telescope body and object end. The cast telescope body is cored out to a suitable thickness, so that although of vastly greater strength and rigidity, it does not weigh as much as the old form of tubular body, collars and stage, while it does away with many separate pieces, which are usually soldered and screwed together, and thus forms THE STRONGEST AND MOST COMPACT LEVEL YET MADE, which with ordinary care should last in perfect adjustment a lifetime. The level is fitted with clamp and tangent adjustment, tribrach levelling, and patent locking plate so that the Level can be used on a wall or masonry as well as on the tripod

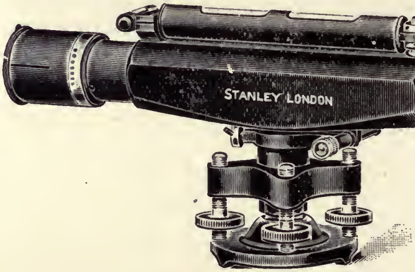
Complete in Mahogany Case with Solid Stand, 10-in., £10 10s. ; 12-in., £12 ; 14-in.	£13	10	0
Framed Stand in place of ordinary, extra	1	0	0
Solid Leather Over-case, with Strap, 10-in., £1 10s. ; 12-in., £1 14s. ; 14-in.	1	18	0

Please send for "K. 153" Catalogue.

STANLEY SURVEYING INSTRUMENTS

TRADE **STANLEY** MARK

NEW ENGINEER'S DUMPY LEVEL.



The demand for our New Form Solid Gun Metal Bodied Surveyor's Level has grown to such an extent that it far exceeds that of all other makes put together. It is acknowledged to be the STRONGEST AND MOST COMPACT LEVEL MADE. Hitherto we have only stocked it with 3-screw or tribrach levelling, but as we have had many requests to supply it with 4-screw levelling by those who still prefer the older method, we have arranged to hold stock of this form in all sizes. The 4-screw arrangement is of our improved design, of great strength and far greater wearing qualities than the old fashioned parallel plates, and the lower plate is fitted with feet to permit of the instrument being used without its stand.

The instruments are fitted with clamp and tangent, highest-class ground and figured bubble, and our finest object glasses.

The diaphragm may be either our improved Platinum-Iridium points, webs or lines on glass, at the option of the purchaser.

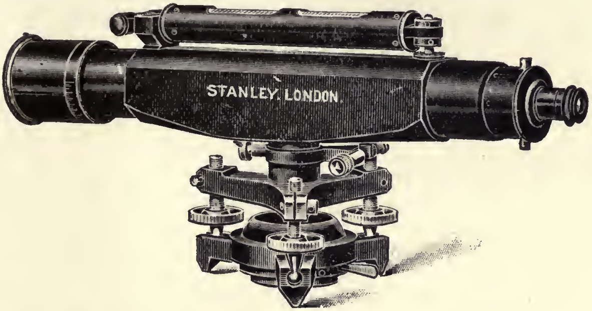
Prices complete in Mahogany Case with Solid Stand, 10-in., £10 10s. ; 12-in., £12 ; 14-in.	£13	10	0
Framed or Sliding Stand, extra	1	0	0
Leather Over-cases, 10-in., £1 10s. ; 12-in., £1 14s. ; 14-in.	1	18	0

STANLEY SURVEYING INSTRUMENTS

TRADE **STANLEY** MARK

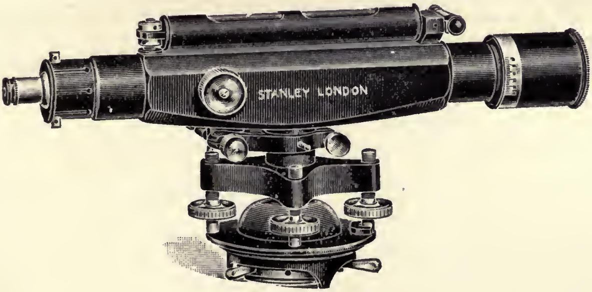
PATENT QUICK-SETTING LEVELS.

THREE-SCREW.


STANLEY. LONDON.

QUICK SETTING ENGINEER'S LEVEL, similar to the foregoing, but with the Stanley Patent Quick-Setting Spherical Joint, 10-in., £12 ; 12-in., £13 10s. ; 14-in. £15 0 0

FOUR-SCREW.

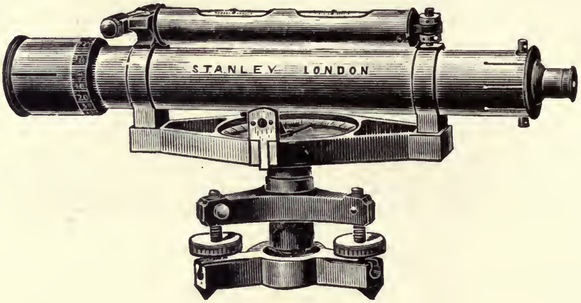


STANLEY'S NEW ENGINEER'S LEVEL, as above illustration, with Four-Screw Quick Levelling, 10-in., £12 ; 12-in., £13 10s. ; 14-in. £15 0 0

STANLEY SURVEYING INSTRUMENTS

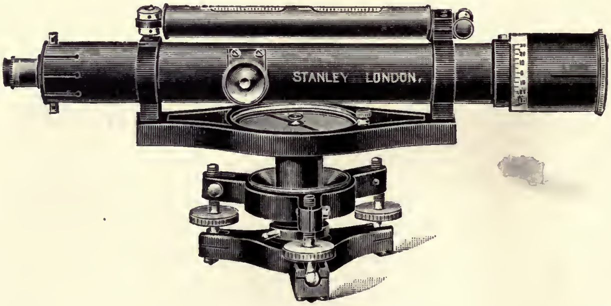
TRADE **STANLEY** MARK

NEW MODEL LEVEL (PATENTED).



PRICES.

	£	s.	d.
With aluminium compass, prism reading, 18-in., £18 10s.; 16-in., £16 10s.; 14-in., £14 10s.; 12-in.	£13	0	0
Without compass, 14-in., £13; 12-in.	11	10	0
Any of the above with framed Stand, in place of ordinary, extra	1	0	0
Any of the above with Clamp and Tangent, extra	0	15	0
Solid Leather Over-case, with Strap, for 18-in., 52s.; 16-in., 47s.; 14-in., 42s.; 12-in.	1	18	0


STANLEY LONDON.

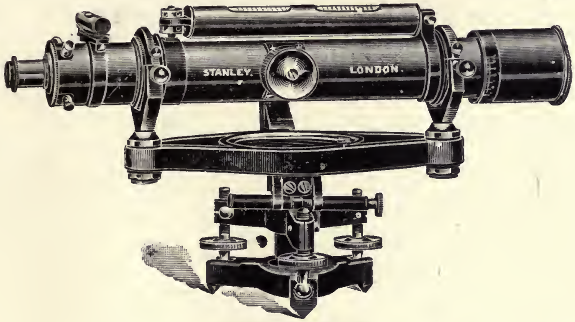
As above, but with the addition of the Stanley Quick-Setting Ball Joint.

	£	s.	d.
With compass, 16-in., £18 10s.; 14-in., £16 10s.; 12-in.	£15	0	0
Without compass, 16-in., £17 10s.; 14-in., £15; 12-in. ...	13	10	0

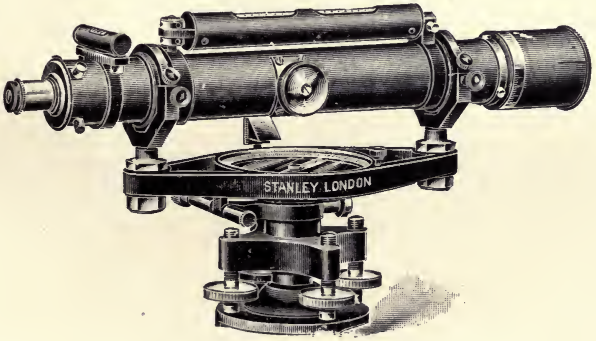
STANLEY SURVEYING INSTRUMENTS

TRADE **STANLEY** MARK

IMPROVED Y LEVELS.



THREE-SCREW



FOUR-SCREW.

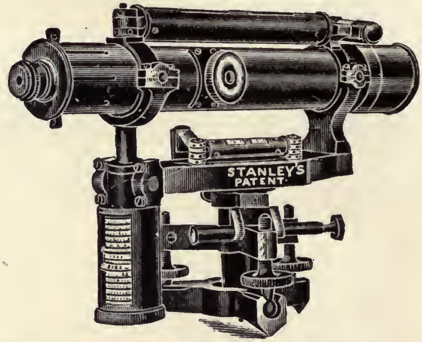
As many still prefer **Y** Levels to the Dumpy form, we have devoted much attention to improving the construction of these. The telescope is of the highest quality with large object glass, and is supported in strong gun-metal collars, with hinged clips and lock screws. The lower plate is of our original design, which permits the instrument being used without its stand, if required. The instrument has clamp and tangent adjustment, and is supplied with a Solid Mahogany Case and Stand.

With prism reading compass, 14-in., £17; 16-in., £18; 18-in.	£20	0	0
Without compass, 14-in., £16; 16-in., £17; 18-in. ...	19	0	0
Framed Stand in place of ordinary, extra	1	0	0
Leather Over-case, extra, 14-in., 42s.; 16-in., 47s; 18-in.	2	12	0

STANLEY SURVEYING INSTRUMENTS

TRADE **STANLEY** MARK

GRADIOMETER (PATENT).



This instrument is designed for taking vertical inclines at fixed small angles for Railways, Irrigation, Drainage Works, etc., etc., by means of an open extended scale, which may be conveniently and distinctly read without the use of a vernier.

It is also the most rapid levelling instrument yet made, as the telescope can be put level instantly at any sight by moving the drum without any setting up whatever by the levelling screws. When the drum is at zero it forms an ordinary level of the most approved form.

The gradiometric arrangement is effected by the telescope being mounted in trunnions, one being adjustable vertically; the amount of elevation or depression being indicated by a drum graduated to read rise or fall either from 1 in 12 to 1 in 1,200; or percentage gradients from ·08 to 8. Please state when ordering which graduation is desired.

The additional parts do not increase the size and add little to the weight.

It is fitted with a SUBTENSE DIAPHRAGM FOR MEASURING DISTANCES, and a clamp and tangent adjustment to facilitate setting the points to the graduations of the levelling staff.

For levelling on steep inclines it also saves a great number of settings up, as instead of levelling for say every 10 feet rise or fall, the gradient of the total distance can be taken, and also the distance by stadia reading, and by reference to a gradient table the difference of level can at once be seen; or if drum is divided to percentage gradients no table is required, as the difference in height is whatever percentage of the distance the drum is set to when the distance reading is taken.

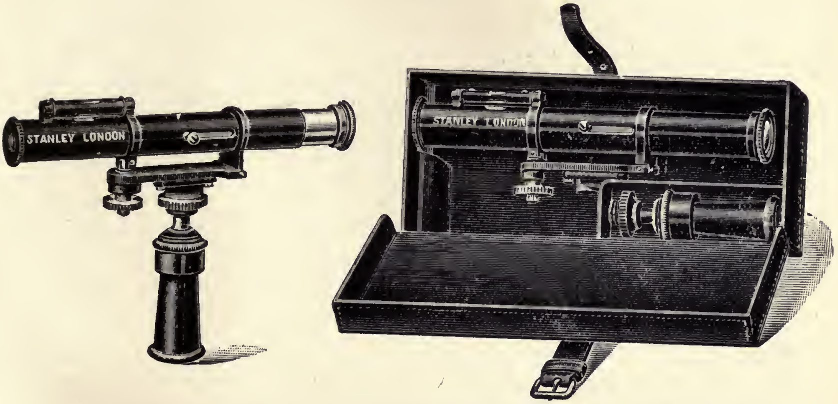
Tacheometrical measurements at distances beyond which it is possible to read a staff can be taken with great accuracy by means of the gradiometer screw and a stadia rod with targets.

14-in., complete, with Aluminium Prism-reading Compass, Clamp and Tangent, Solid Tripod Stand	£20	0	0
Extra for Framed Stand in place of the usual form ...	1	0	0

STANLEY SURVEYING INSTRUMENTS.

TRADE **STANLEY** MARK

POCKET TELESCOPIC REFLECTING LEVEL.



This is an accurate and very simple instrument, and will be found especially useful for all work where a very portable level is required. The spirit bubble, web, and object are all seen in the telescope at one observation, and it is so simple in use that anyone without previous experience can use it without difficulty.

The bubble as seen in the eye-piece is reflected by a silver reflector to the diaphragm where the image from the object glass is formed, and when the bubble is adjusted by the milled head under the stage to the centre of its run, the object which coincides with the bubble is in a level line with the line of collimation of the instrument.

It is packed in a leather case with a ball and socket fitting for a stick or Jacob Staff.

Price, complete £2 10 0

SOPWITH LEVELLING STAVES.

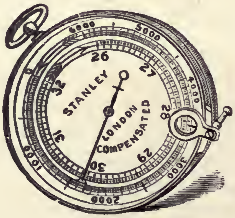
Made entirely of well-seasoned mahogany, the bodies screwed together and strongly bound with brass. Painted readings, either Sopwith or metre pattern, 14-ft. or 4.25 metres, £2 5s ; 16-ft. or 5 metres, £3 ; 18-ft. or 5.75 metres £3 10 0

STANLEY SURVEYING INSTRUMENTS

TRADE **STANLEY** MARK

PRISMATIC COMPASSES, ETC.

Prismatic Compass, brass, with Shades and Mirror, Aluminium ring, in solid Leather Case, 2½-in., £3 5s.; 3-in., £3 10s.; 3½-in., £4; 4-in., £4 10s.; 4½-in., £5; 5-in., £5 10s.; 6-in.	£6	10	0
In Aluminium, 2½-in., £3 15s.; 3-in., £4 5s.; 3½-in., £4 10s.; 4-in., £5; 4½-in., £5 12s.; 5-in., £6 5s.; 6-in.	7	5	0
Stand fitted to Prismatic	1	4	0
Captain Abney's Pocket Level and Clinometer ...	1	18	0
Ditto, large, with Telescope, reading to minutes, with rack adjustment	6	0	0



STANLEY ANEROIDS.

Aneroid Barometer, 3-in. or 4½-in., Stanley's Improved, specially for altitude measurements. Of very refined workmanship, and has a new and exact system of reading. It may be relied upon for comparing depths of mines, altitudes, etc., within a single yard or less; in case	£6	0	0
As above, in Aluminium, weight 3½ lbs., in Sling Leather Case	6	10	0
Tourist's Pocket Aneroids, with altitudes, £1, £2 10s., and	4	0	0

TRADE **STANLEY** MARK

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Drawing Instruments of the very highest class made throughout in our own workshops. Last a lifetime.

Every Article for Engineers and Surveyors in stock. All of the highest possible quality.

Drawing Office Stationery at the lowest prices. A very large stock kept.

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